GRANIT - 2014 Workshop

Measuring the charge of the free Neutron with qBounce

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Outline

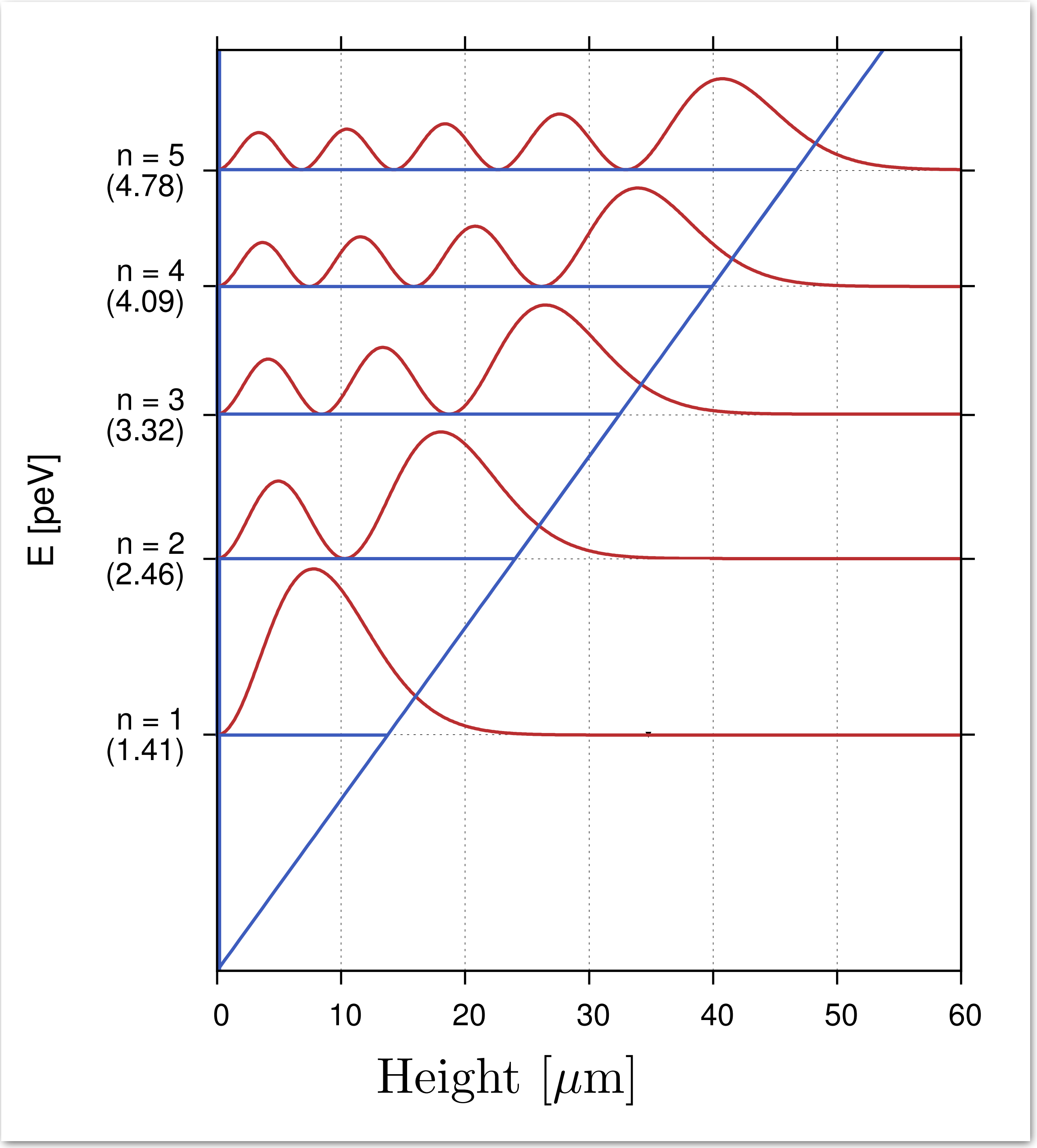
- Gravity Resonance Spectroscopy
- Ramsey Spectroscopy
- Neut
- Outlook

Talk tomorrow by Tobias Jenke

Gravity Resonance Spectroscopy - 2014

$$\left(-\frac{\hbar^2}{2m_n}\frac{\partial^2}{\partial z^2}+m_n g z\right)\Psi_n(z)=E_n\Psi_n(z)$$

$$\Psi(0)\overset{!}{=}0$$



Solution:

$$\Psi(z)=aAi(z)+bBi(z)$$

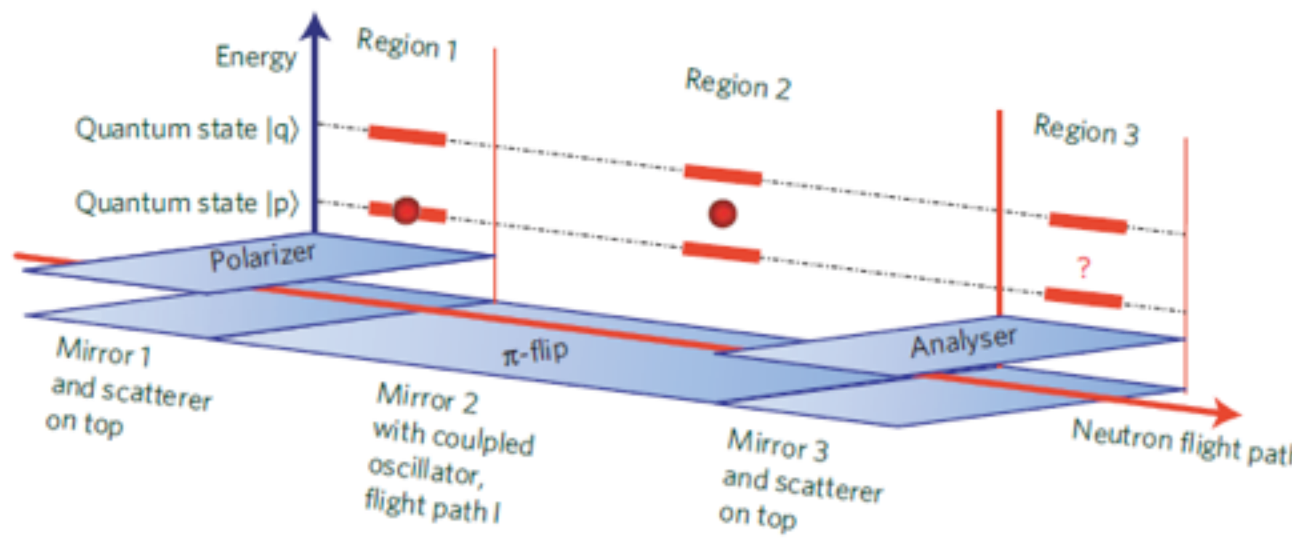
$$E_0=m_n g z_0 \qquad z_0=\sqrt[3]{\frac{\hbar^2}{2m_n^2 g}}$$

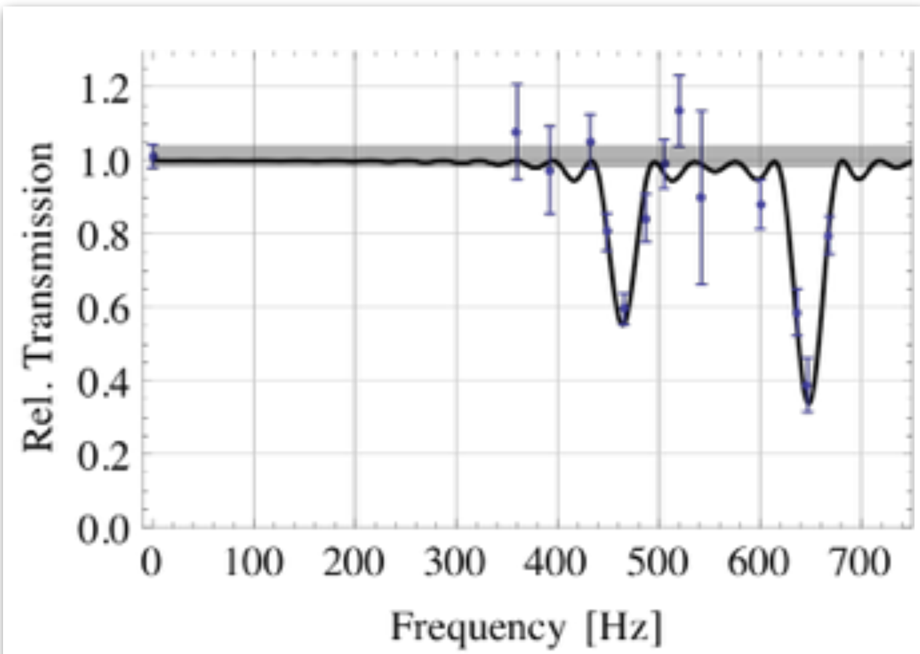
$\Rightarrow$ simple qm. system

with few dependencies !

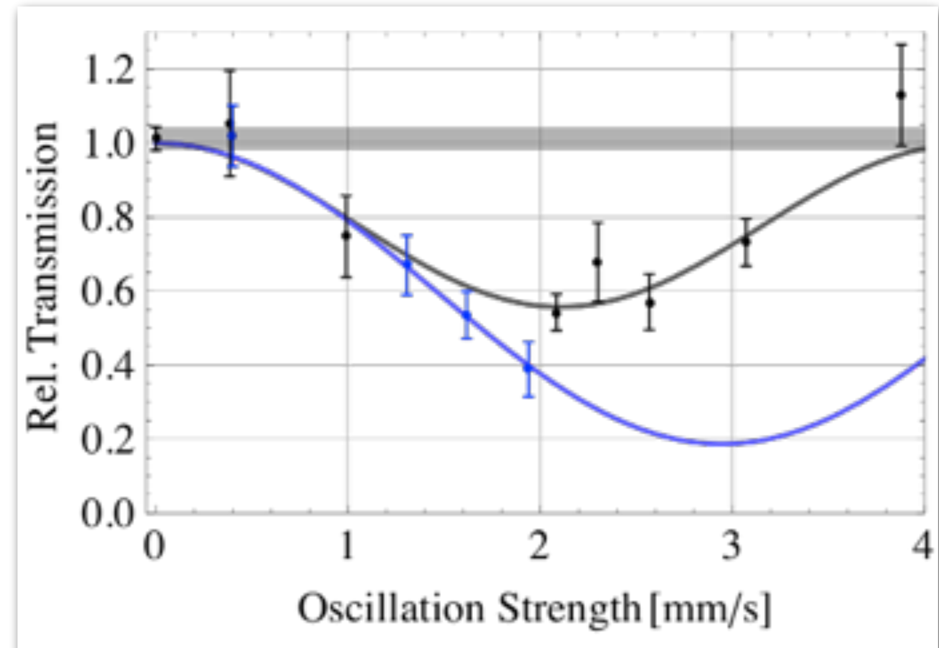
Rabi's method (2012)
Talk by G. Cronenberg

$$\omega_{pq} = \frac{(E_q - E_p)}{\hbar}$$





by courtesy of G. Cronenberg



by courtesy of G. Cronenberg

$g, \hbar, m \rightarrow$ determine energie level

ideal for systematic test of the quantum system at hand

Outline

- Gravity Resonance Spectroscopy
- Ramsey Spectroscopy
- Neutron Charge Measurement
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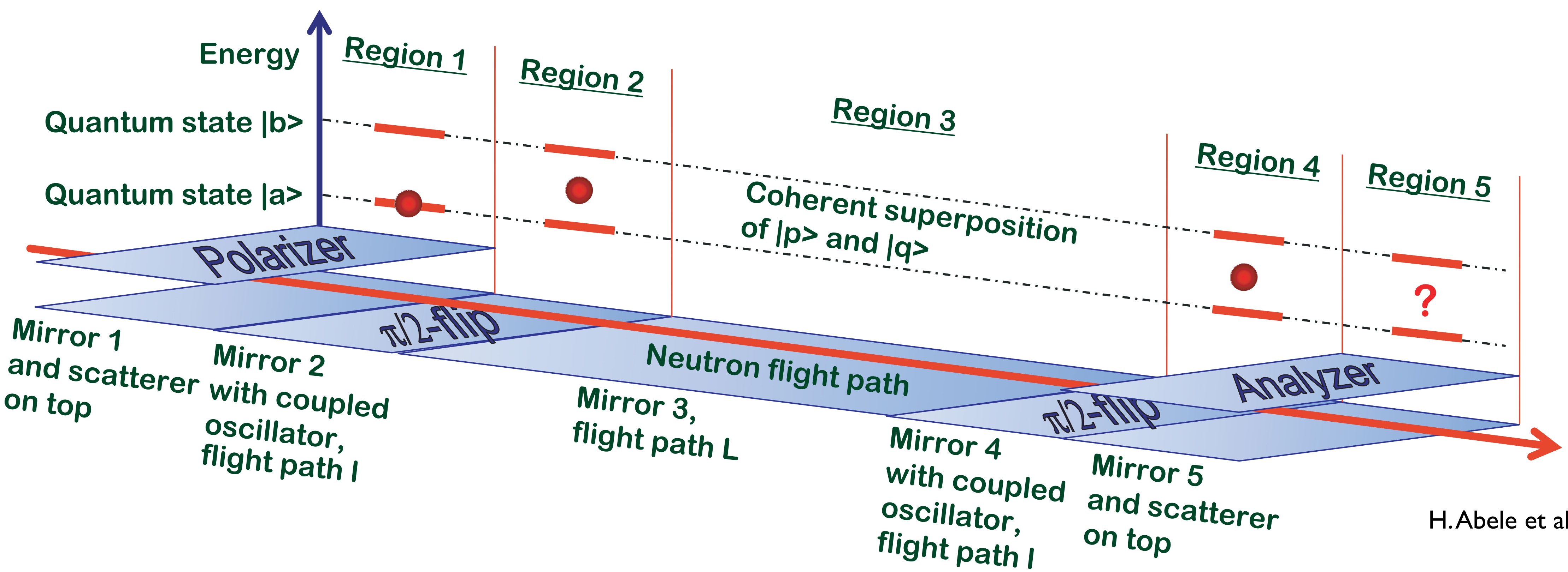
Ramsey Spectroscopy

Ramsey's Method of separated oscillating fields
⇒ distinct evolution region!

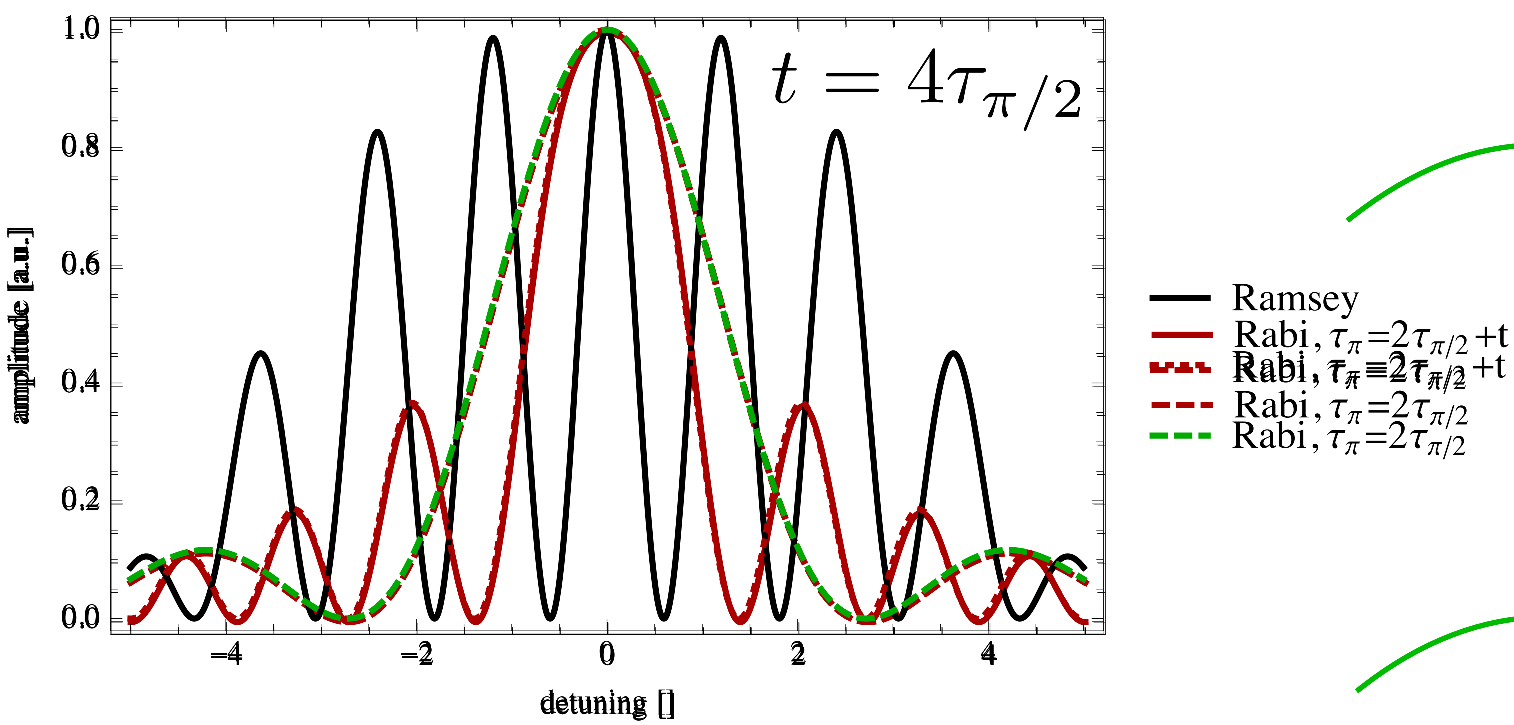


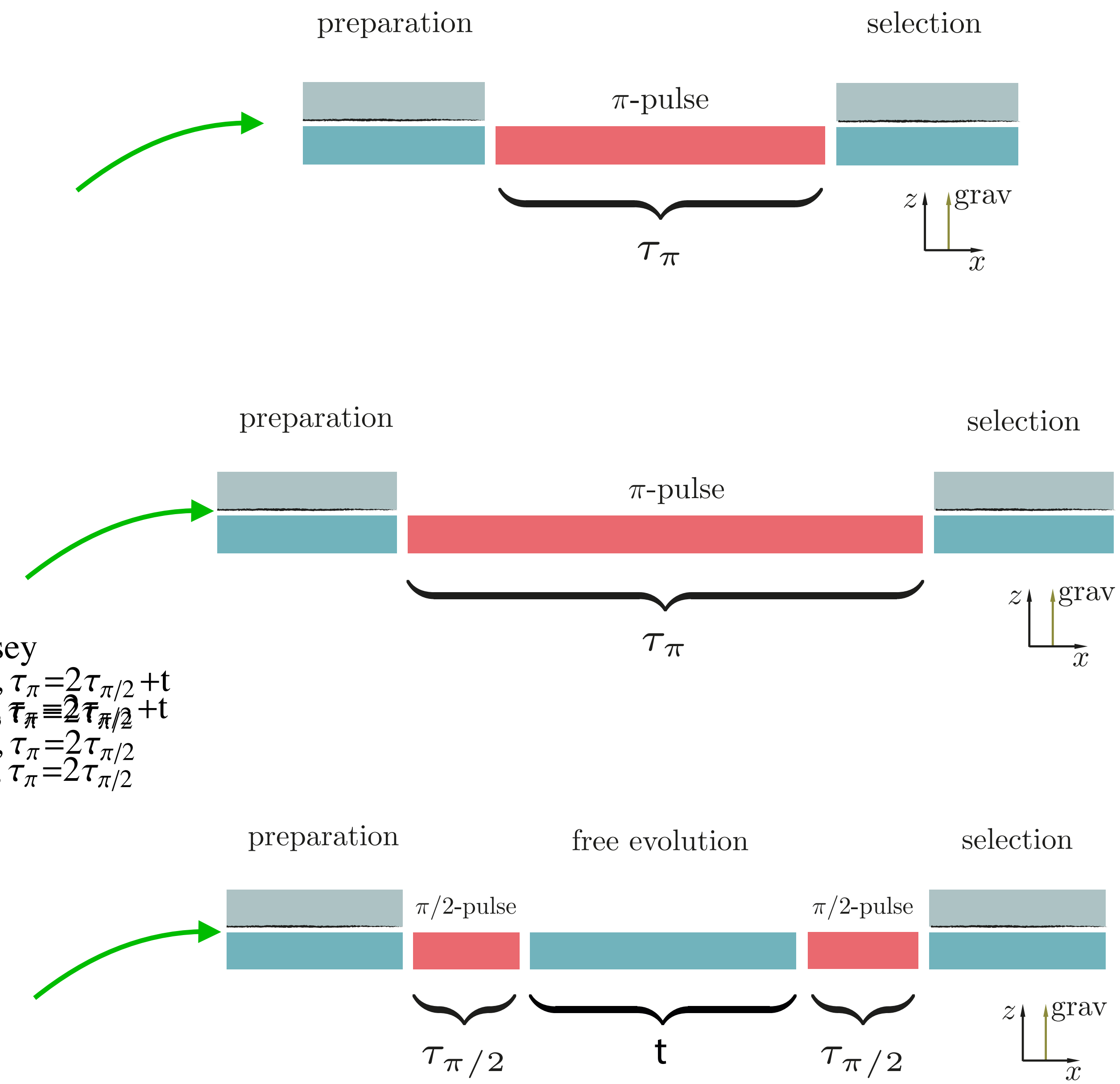
H. Abele et al., 2010

Ramsey Spectroscopy

steep slope ⇒ high sensitivity

$$\delta q \propto 1/\left(\frac{\partial r(\nu)}{\partial \nu}\right)$$

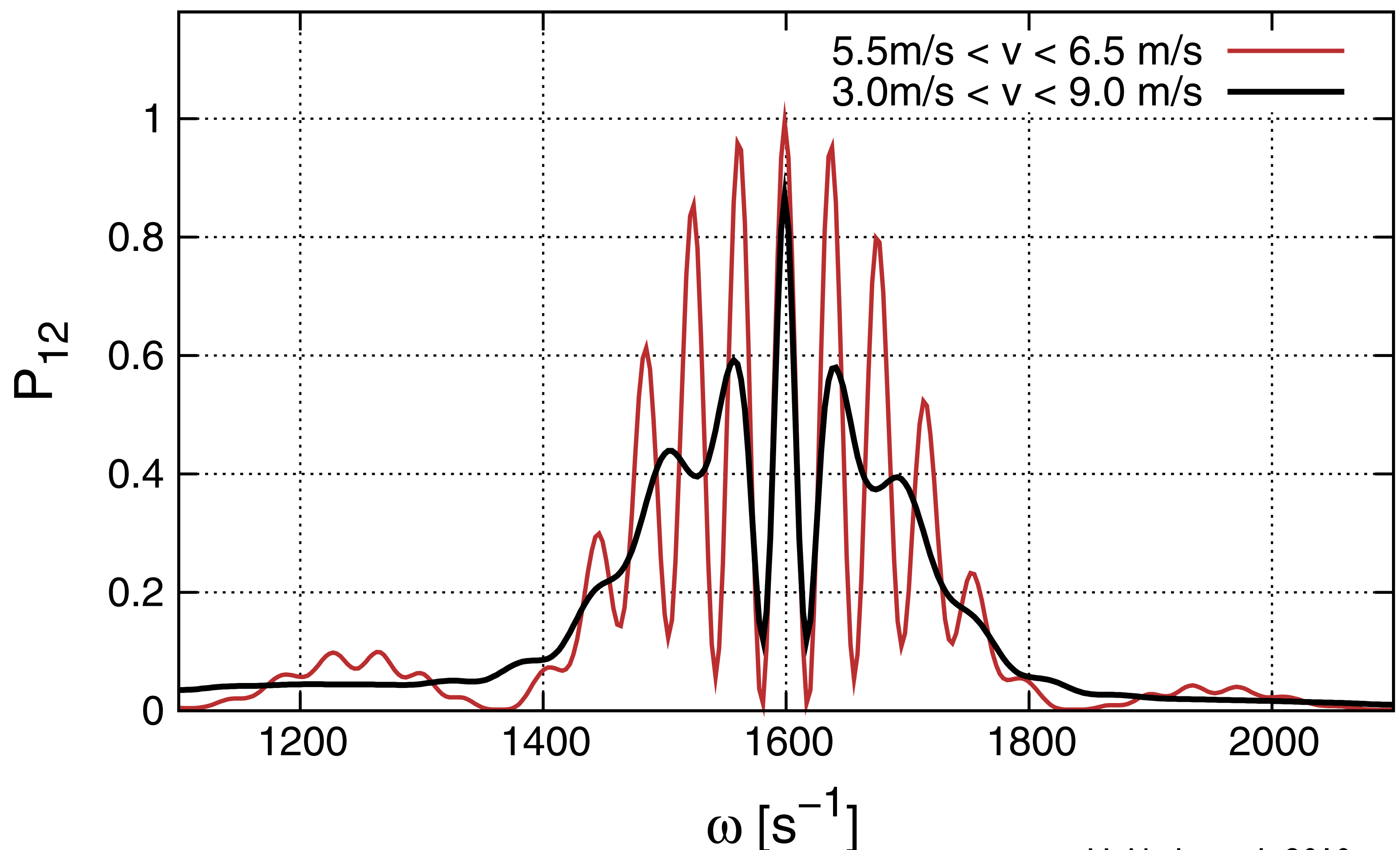




smaller mirrors ⇒ clean vibrations

Ramsey Spectroscopy

robust middle peak shape with different velocity distributions



H. Abele et al., 2010

⇒ very stable middle region

⇒ more efficient usage of the beam

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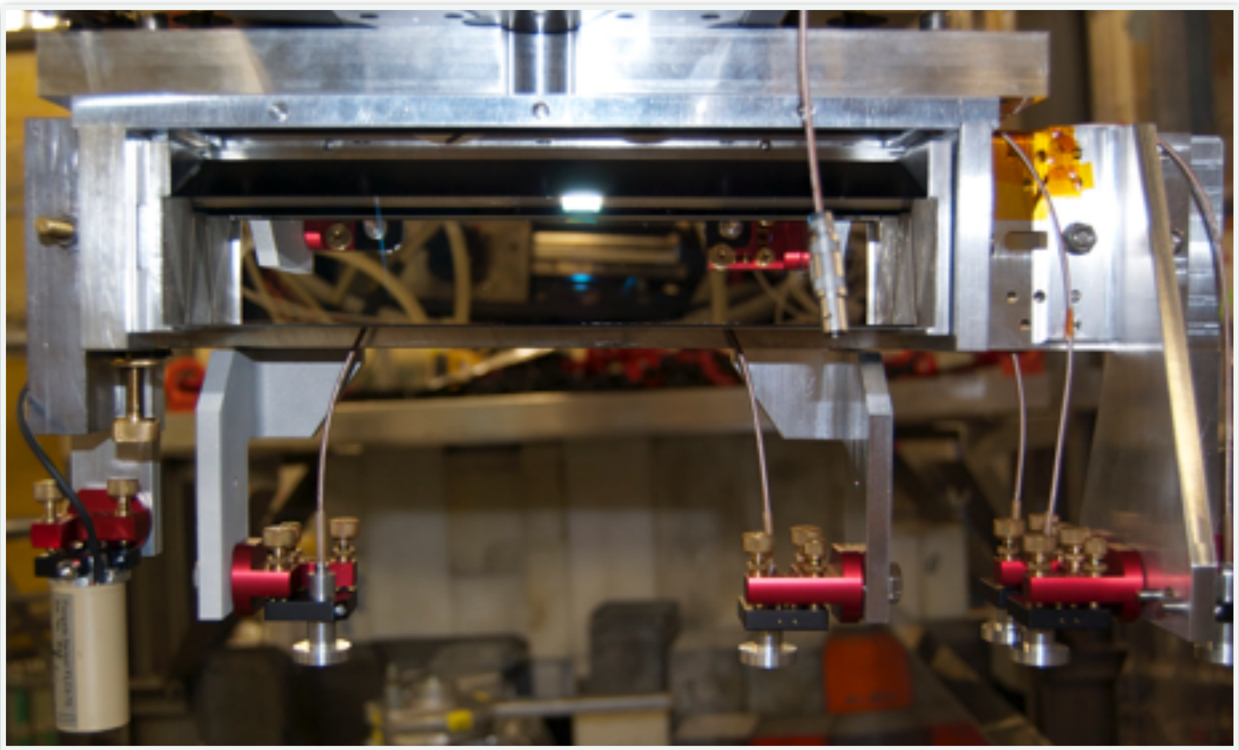
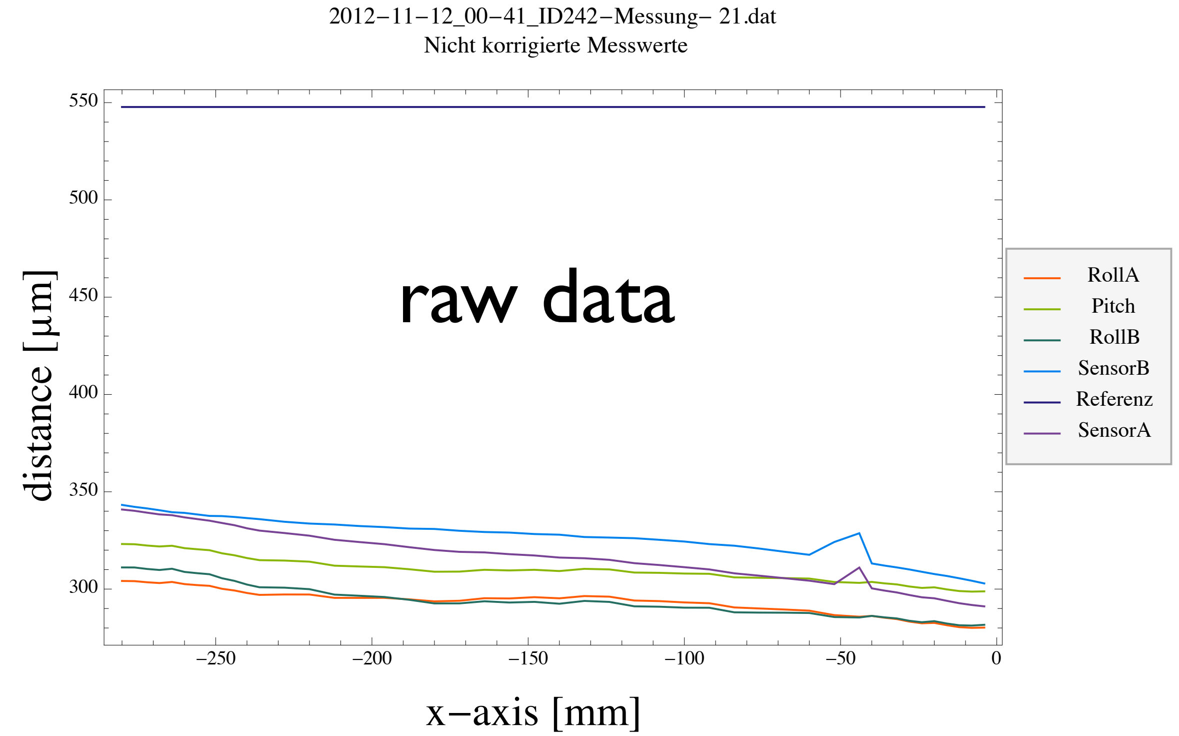
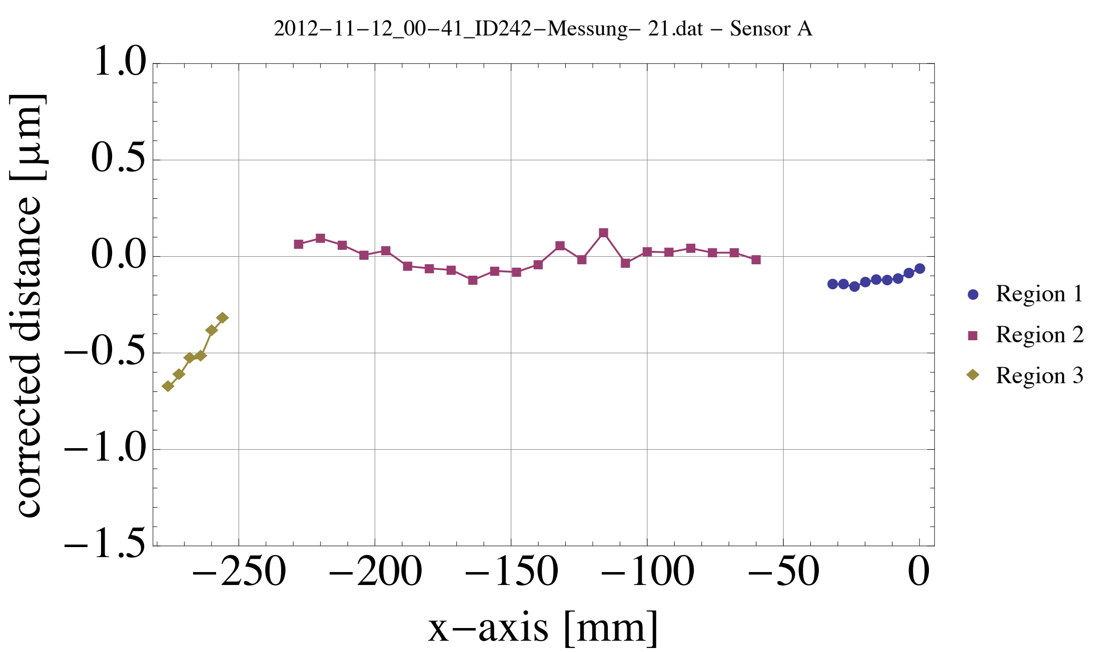
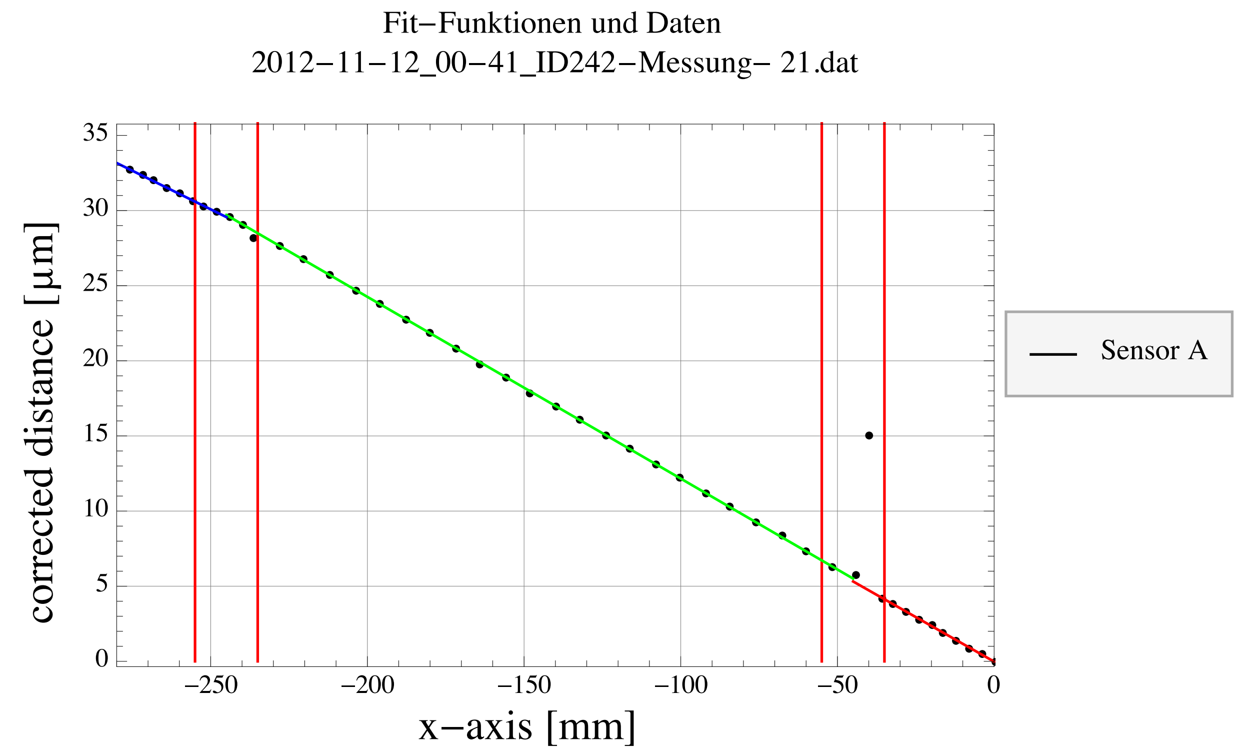
Ramsey Spectroscopy

steps and mirror orientation









steps < 0.5µm

slope difference < 30µm

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conclusion

- steeper slope comparable rabi setup
- small vibration area
- more efficient usage of velocity distribution
- easy extendibility ⇒ i.e. electric fields

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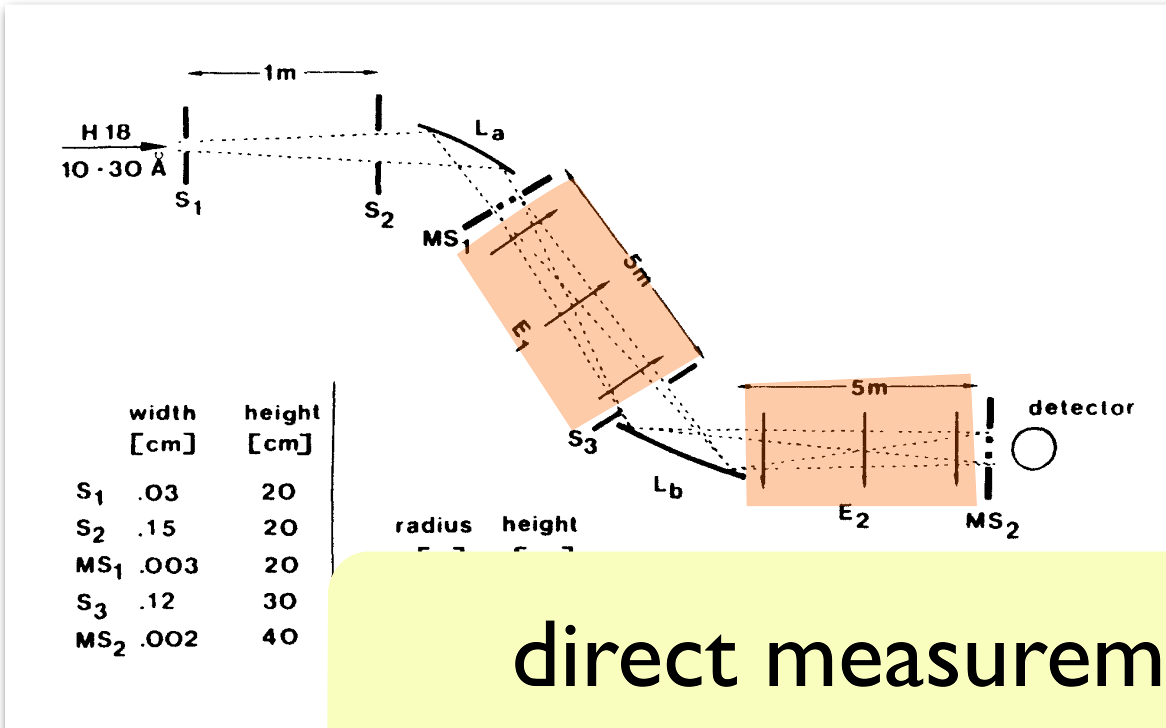
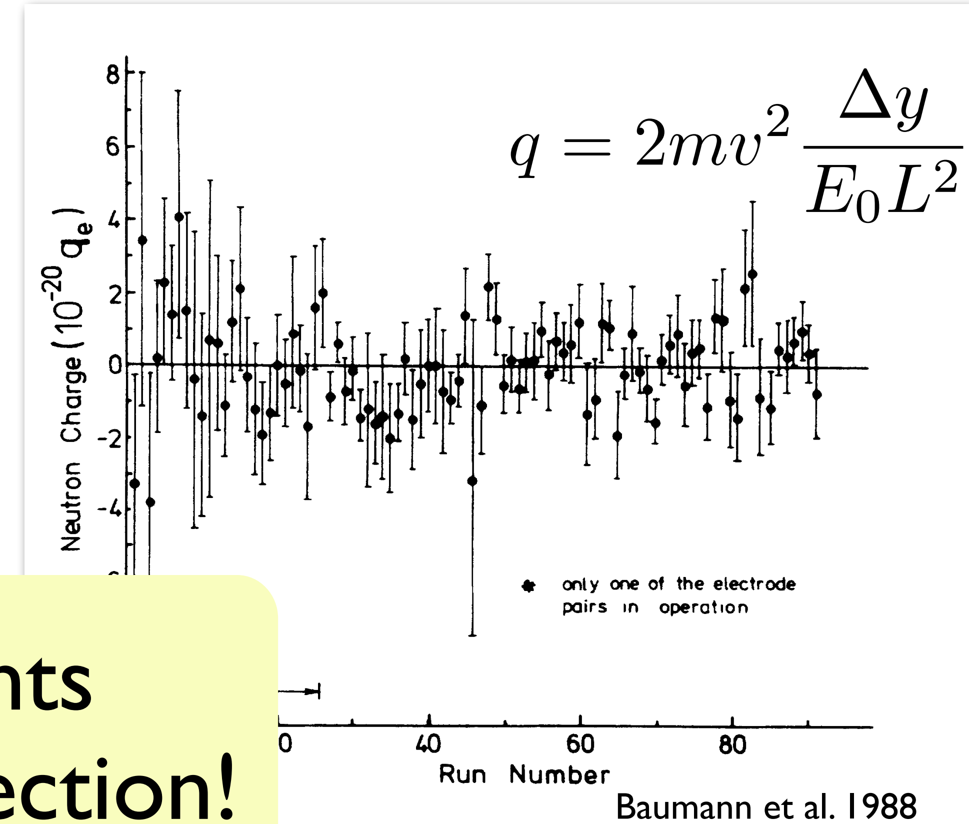
Priority Programme 1491

- Research Area A: *CP-symmetry violation and particle physics in the early universe*
  - Neutron EDM $\Delta E = 10^{-23}$ eV
- Research Area B: *The structure and nature of weak interaction and possible extensions of the Standard Model*
  - Neutron β-decay V – A Theory
- Research Area C: *Test of gravitation with quantum interference*
  - Neutron bound gravitational quantum states
- Research Area D: *Charge quantization and the electric neutrality of the neutron*
  - Neutron charge
- Research Area E: *New measuring techniques*
  - *Particle detection*
  - *Magnetometry*
  - *Neutron optics*

Neutron Charge Measurement

Baumann et al. (1988)





$$q = 2mv^2 \frac{\Delta y}{E_0 L^2}$$

direct measurements through Neutron deflection!

PHYSICAL REVIEW D VOLUME 37, NUMBER 11

1988

Experimental limit for the charge of the free neutron

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ILL

...ceived 12 November 1987)

In agreement with the commonly accepted neutrality of the free neutron, its charge q_n was found

"In agreement with the commonly accepted neutrality of the free neutron, its charge q was found to be $(-0.4 \pm 1.1) \times 10^{-21} q_e$ electron charges."

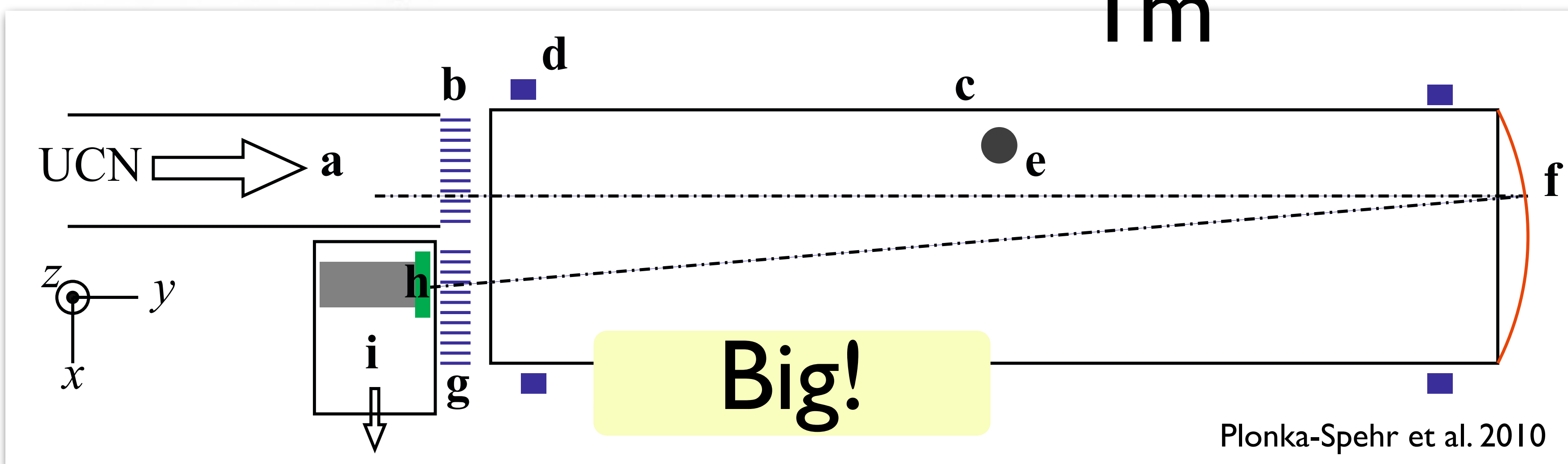
Neutron Charge Measurement

Borisov et al. (1988) → Plonka-Spehr et al. (now)

The Apparatus

Definite setup:

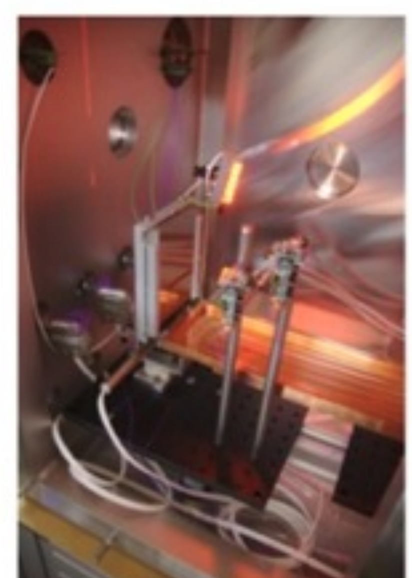
1m



Plonka-Spehr et al. 2010

Aligning the optical components (fully automatic):

The gratings contain fix reference points with photodiodes to scan for the adjustment lasers and detect tilts to a level of $\Delta\alpha = 0.07\mathrm{mRad}$.
The mirror is illuminated by an adjustment laser. This laser is projected on two screens, which are read out by cameras. So, the tilt can be corrected to a level of $\Delta\alpha = 0.53\mathrm{mRad}$.



The overall angular sensitivity must be $\leq 1.33\mathrm{mRad}$ for all optical elements.

by courtesy of C.Siemensen

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Neutron Charge Measurement

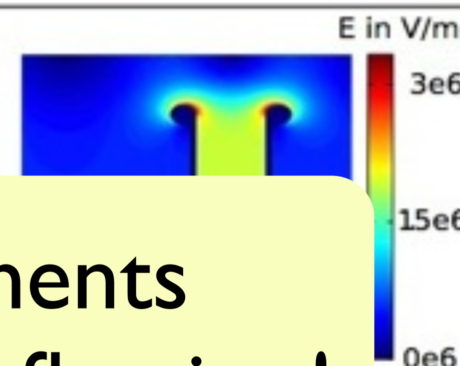
Borisov et al. (1988) → Plonka-Spehr et al. (now)

Outlook

Electric field:

The electrode spacing will be 10 cm. A dedicated design prevents triple points and keeps field stresses below 4 MV/m. A symmetric voltage supply of 200 kV …

This attra… $q \approx 1 \cdot 10$…



direct measurements through Neutron deflection!

Overall …

The sensitivity of this measurement is $\delta q_n \propto \left[E\, t_{\mathrm{fly}}^2 \sqrt{\tau_{\mathrm{meas}}} \frac{\mathrm{d}N}{\mathrm{d}x} \right]$

The former experiment of Borisov had a sensitivity of $\delta q_n = 9 \cdot 10^{-20} q_e/\sqrt{\mathrm{d}}$. Mostly, the sensitivity is restricted by technical boundaries as the UCN flux of the neutron source, the effect of high voltage breakdown and aberration. The right side of the tabular shows those boundaries.

Modification	**Gain factor in sensitivity**	**Gain limit (hypothetic)**
Increase of slope	$\boxed{3.5}$ - 7	<10
Enhancement of electric field	1-2	<3.5
Extension of the flight path	$\boxed{2.25}$	1
Higher UCN Flux	$\boxed{2.5}$	1
Lower Flux due to extended path	$\boxed{0.5}$	
Overall Gain:	$\boxed{9}$ - 35	

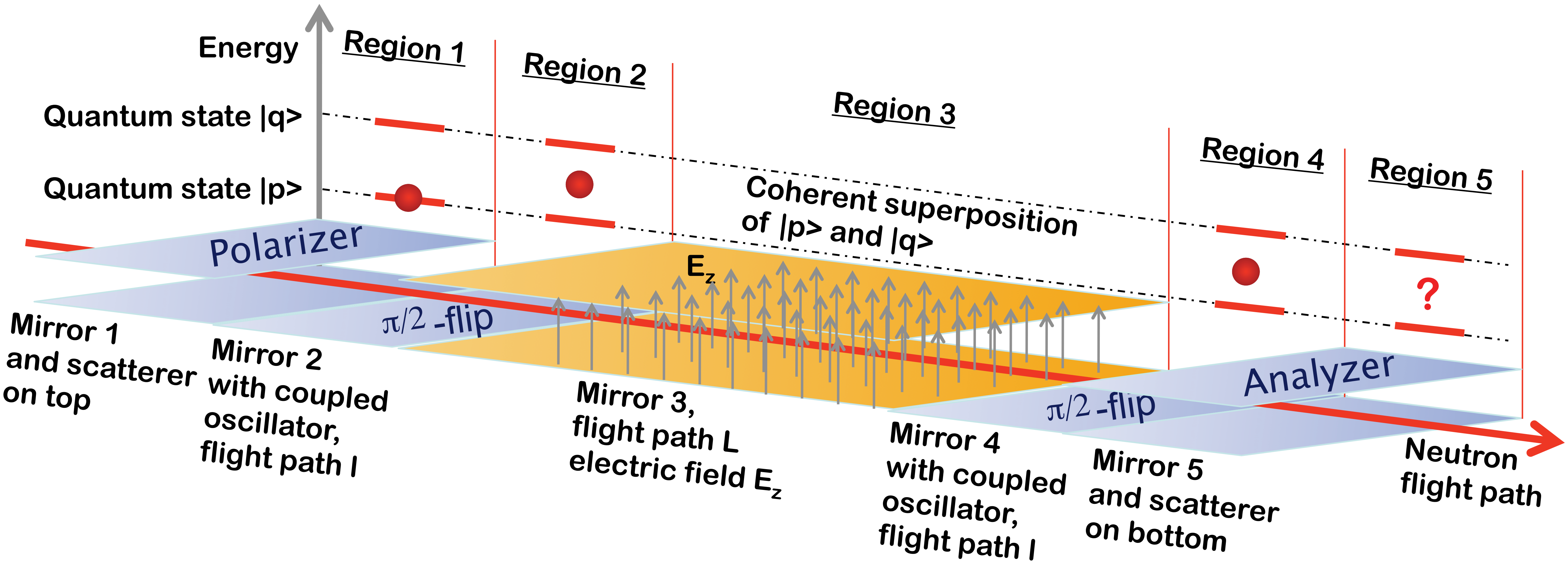
The accomplished modifications are marked green.

$$\delta q \approx 2.6 \times 10^{-20} q_e$$

by courtesy of C.Siemensen

lets get small!

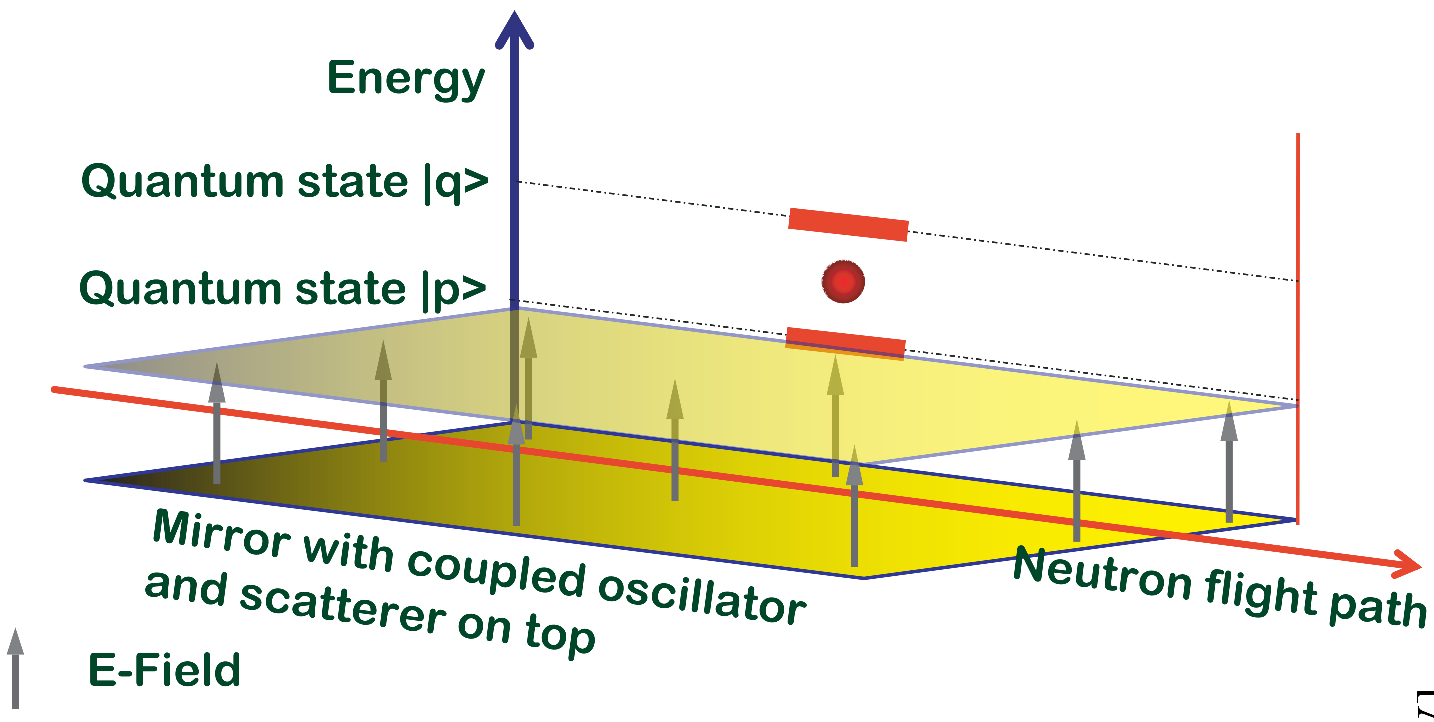
combine GRS with electric fields



K. Durstberger-Rennhofer et al., 2011

electrode distance not in scale

GRS and the Neutron charge

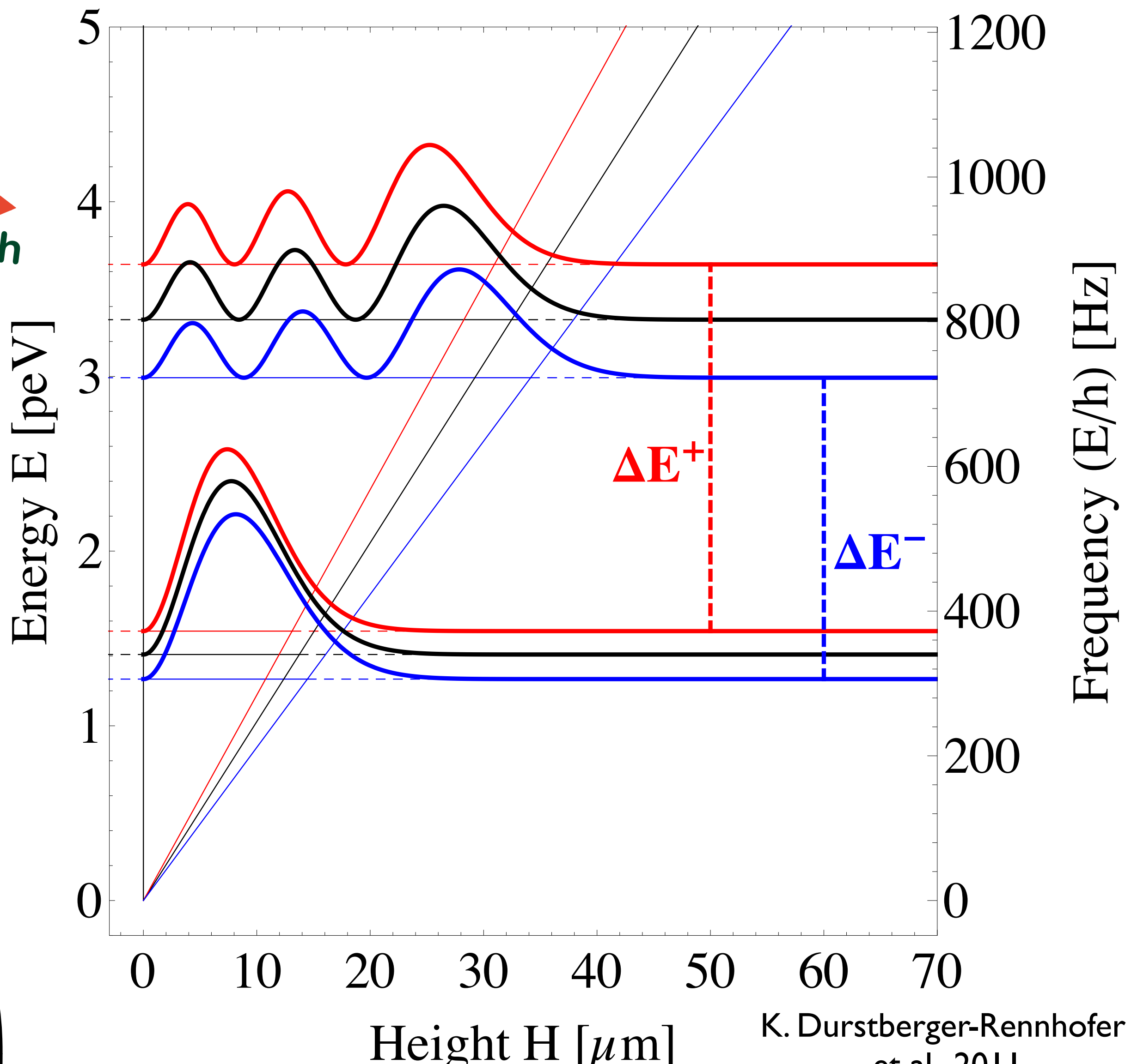


K. Durstberger-Rennhofer et al., 2011

$$H = -\frac{\hbar^2}{2m}\frac{\partial^2}{\partial z^2} + mgz \pm q|E_z|z$$

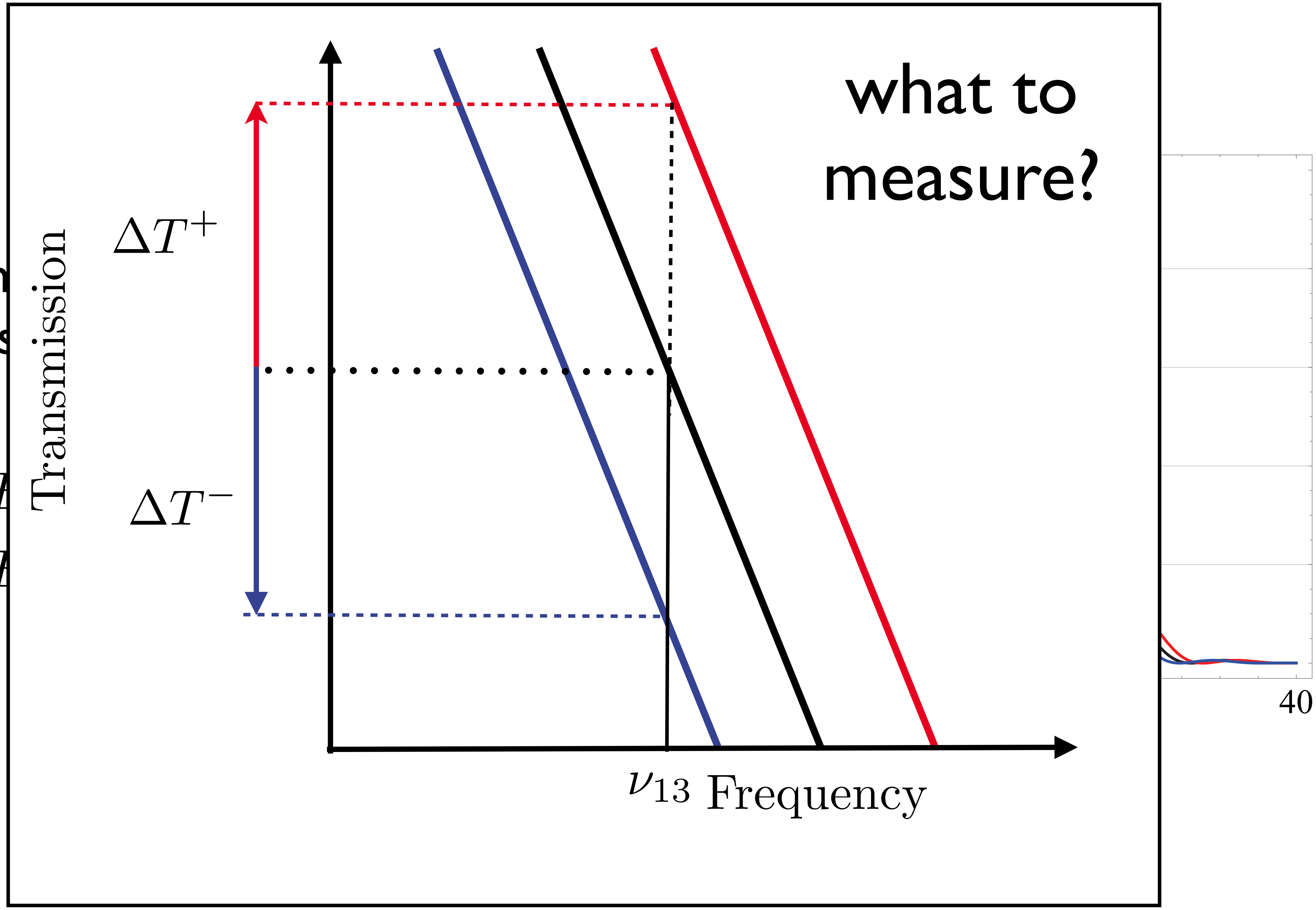
$$\Delta E_n = \Delta E_n^+ - \Delta E_n^-$$

$$\Delta\nu = \nu_{pq}\left(\sqrt[3]{\left(1 \pm \frac{q|E_z|}{mg}\right)^2} - 1\right)$$



K. Durstberger-Rennhofer et al., 2011

Neutron Charge Measurement



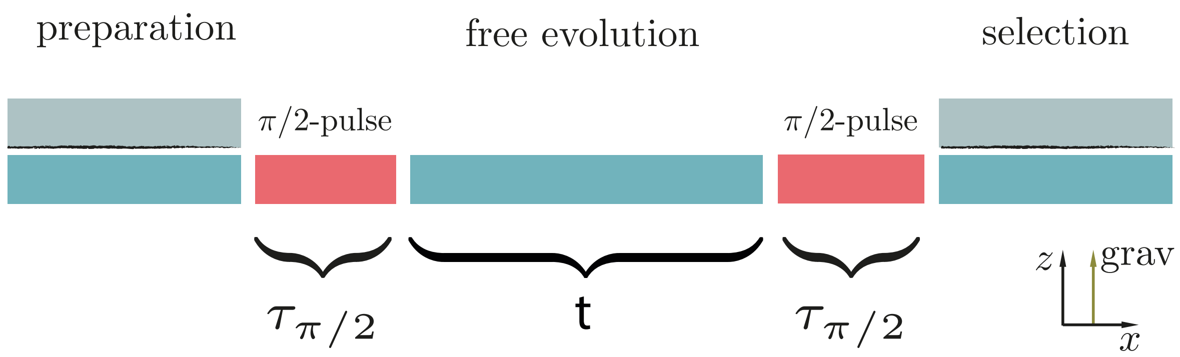
$$\delta q = \frac{\sqrt{2}\bar{r}}{\sqrt{N}} \cdot \frac{1}{\frac{\partial r(\nu)}{\partial \nu}|_{\nu_0} \nu_0} \cdot \frac{3}{4} \frac{mg}{E_z}$$

Neutron Charge Measurement

What about sensitivity?

$$\delta q = \frac{1}{\kappa\sqrt{N}} \frac{1}{(\pi t + 4\tau)\nu_{ab}} \frac{3}{4} \frac{mg}{|E_z|}$$

K. Durstberger-Rennhofer & T. Jenke



$$\boxed{\begin{array}{llll} T = \text{one Day} & \bar{r} = 100\,\mathrm{mHz} & E_z = 50\,\mathrm{kV/mm} & \\ \kappa = 1 & t = 0.13\,\mathrm{s} & \tau = 25\,\mathrm{ms} & v_n = 6\,\mathrm{m/s} \end{array}}$$

$|1\rangle \leftrightarrow |3\rangle$

$$\nu_{1,3} = 463\,\mathrm{Hz}$$

$$\delta q = 6.9 \times 10^{-20}\, q_e$$

$|1\rangle \leftrightarrow |6\rangle$

$$\nu_{1,6} = 972\,\mathrm{Hz}$$

$$\delta q = 3.3 \times 10^{-20}\, q_e$$

Neutron Charge Measurement

What are the limits to this approach?

- Vacuum break down in electric fields $(70-80)\,\mathrm{kV/mm}$
  i.e. D.Alpert, et al., (1964)

  $\longrightarrow$ $42\,\mathrm{kV/mm}$ achieved !

  preparatory work in BA thesis,
  L. Schrangerl, M. Spannring
  and M. Iro

- Limited measurement time

  weeks

- Limited counting rate

  $\longrightarrow$ new sources ? $\approx 100\,\mathrm{mHz}$

- Limited interaction time

  $\longrightarrow$ store neutrons? $\approx 0,1\,\mathrm{sec}$

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Outlook

- Implement Ramsey's method of oscillating fields with UCN in earth's gravitational field

T. Rechberger, M. Thalhammer

- Short-term perspective: $\delta q = 5 \times 10^{-20}\, q_e \qquad |1\rangle \leftrightarrow |4\rangle$
- Long-term perspective: improvement of x100

Literature

Thank you for your attention.

V. V. Nesvizhevsky et al., Nature, 415(6869), 297–299. doi:10.1038/415297a (2002)
K. K. Durstberger-Rennhofer et al., Phys. Rev. D 84, 036004 (2011)
N. F. Ramsey, Physical Review, 78(6), 695–699. doi:10.1103/PhysRev.78.695 (1950)
T. Jenke et al., Nature Physics 7, 468-472 (2011)
H. Abele et al., Phys. Rev. D 81, 065019 (2010)
T. Jenke et al., Nucl. Instr. Meth. A 611 318 (2009)
T. Jenke, Dissertation (TU Wien, 2011)

Funding:

FWF Der Wissenschaftsfonds.

NEUTRONS FOR SCIENCE

DFG
Schwerpunktsprogramm 1491

Appendix

Motivation

Observations: The Neutron is electrically neutral and the electric charge is quantized.

Theory: The Standard Model of Particle Physics (three generations), does not have electric charge quantization.

$\longrightarrow$ The value of the charge of the Neutron is in principle not fixed.

Neutron Charge Measurement

42kV/mm achieved, but

spark damage for higher fields