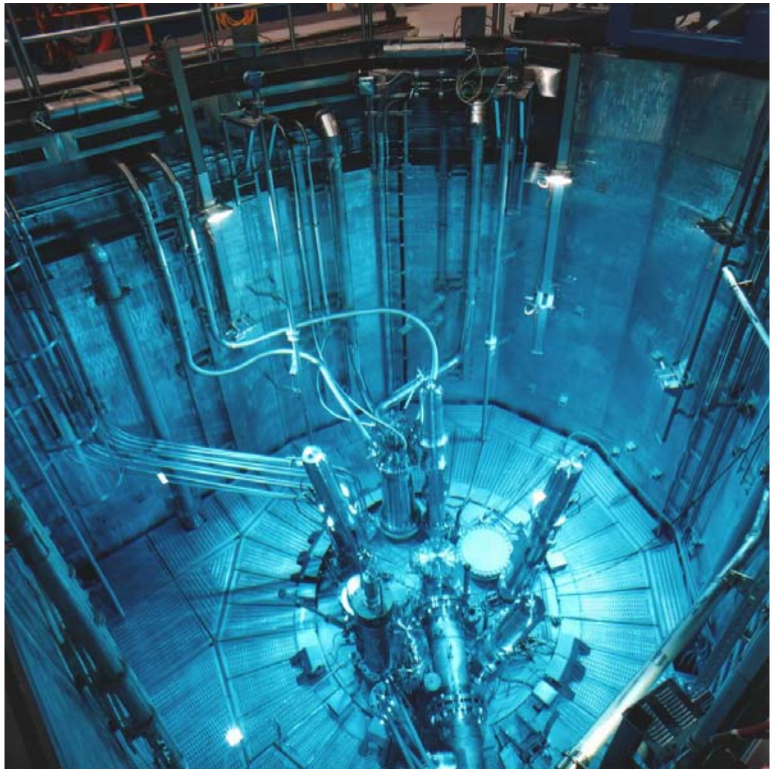
Neutron-Mirror neutron Oscillation Measurement at FRM II



Composition of the Universe

- there is not sufficient visible matter to explain galaxy formation by gravitation theory

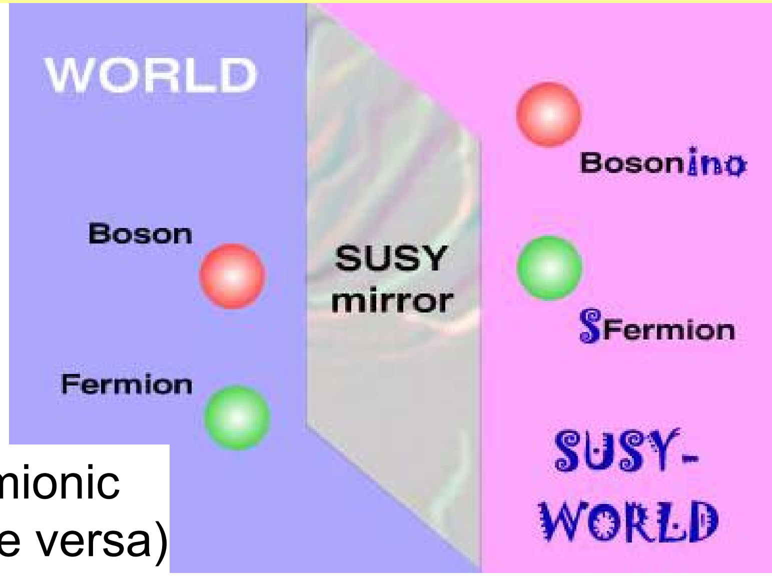
- orbital velocities of stars distant from the centre of galaxies should be smaller than observed

⇨ gravitation of visible matter is not sufficient to keep a galaxy together

4% matter of the standard model
22 % dark matter
74 % dark energy (WMAP-data)

dark: astronomically not detectable
indirect detection needed

What is dark matter?



Proposed suggestions and ideas:

- Supersymmetric Particles
  → every bosonic particle gets a fermionic supersymmetric partner (and vice versa)

- WIMPs Weakly Interacting Particles
  → elementary particles without electric charge
  only weakly interacting, subject to gravitation
  mass of ca. 10-1000 GeV/c^2

- Particles of the mirror world (Lee and Yang 1956)

Mirror matter

Idea of an overall theory to conserve the symmetry of the world.

R-transformation: transformation from world to mirror world

PR-transformation: parity transformation $\vec{r} \rightarrow -\vec{r}$
and transformation from world → mirror world

→ world: only left-handed ν and only right-handed $\overline{\nu}$
mirror world: only right-handed ν' and only left-handed $\overline{\nu}'$

no strong, weak or electromagnetic interactions between world and mirror world

Measuring methods of mirror particles

Detection of mirror matter:

- direct: is not possible, there are no detectors for mirror matter available
- indirect: is possible, detection of disappearance of („normal“) matter

Observation of disappearance of particles from a beam when all other interactions are suppressed.
(Measuring with neutrons: magnetic field-free trajectory)

Measuring value: analysis of the oscillation time
matter → mirror matter → matter

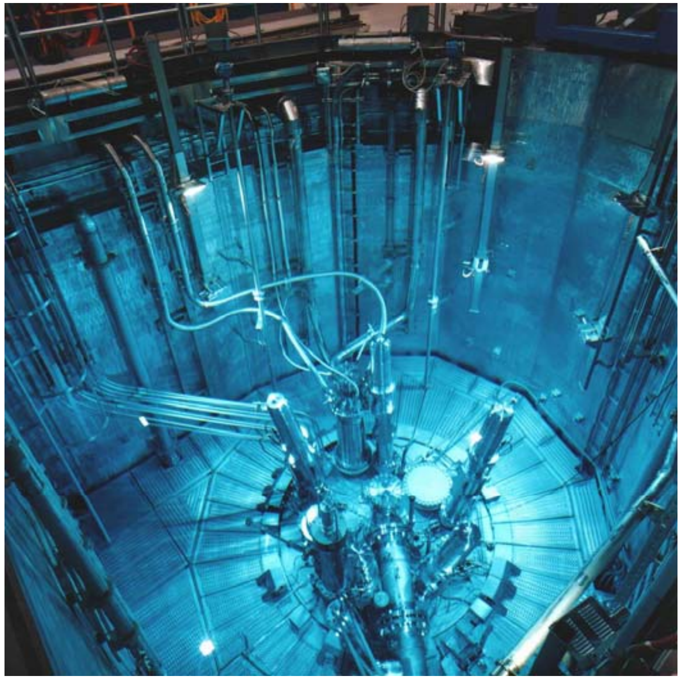
Measurement with neutrons

Neutrons are predestinated for a mirror world measurement because:

• they are neutral,
→ charged particles always produce an electric field that would suppress an oscillation

• they have a long lifetime,
→ a long observation time is available

• high fluxes and efficient high rate detectors are available
→ small statistical error



Measurement

Oscillation from neutron in mirror neutron could
be only possible in a magnetic field-free space:

Measuring of:

- flux of a neutron beam in an external magnetic field

- neutron flux without a magnetic field

measurement time: 500 ms per cycle
time of flight: 17 ms
during switch on and off of the magnetic field,
there is a measuring pause of 100 ms
total measurement time: ca. 26.5 hours at the FRM II in Munich

for each cycle: $$\frac{\textit{n-rate without a magnetic field}}{\textit{n-rate with a magnetic field}}$$

→ a large number of ratios

Experiment-Spectrometer

Spectrometer: RESEDA at FRM II

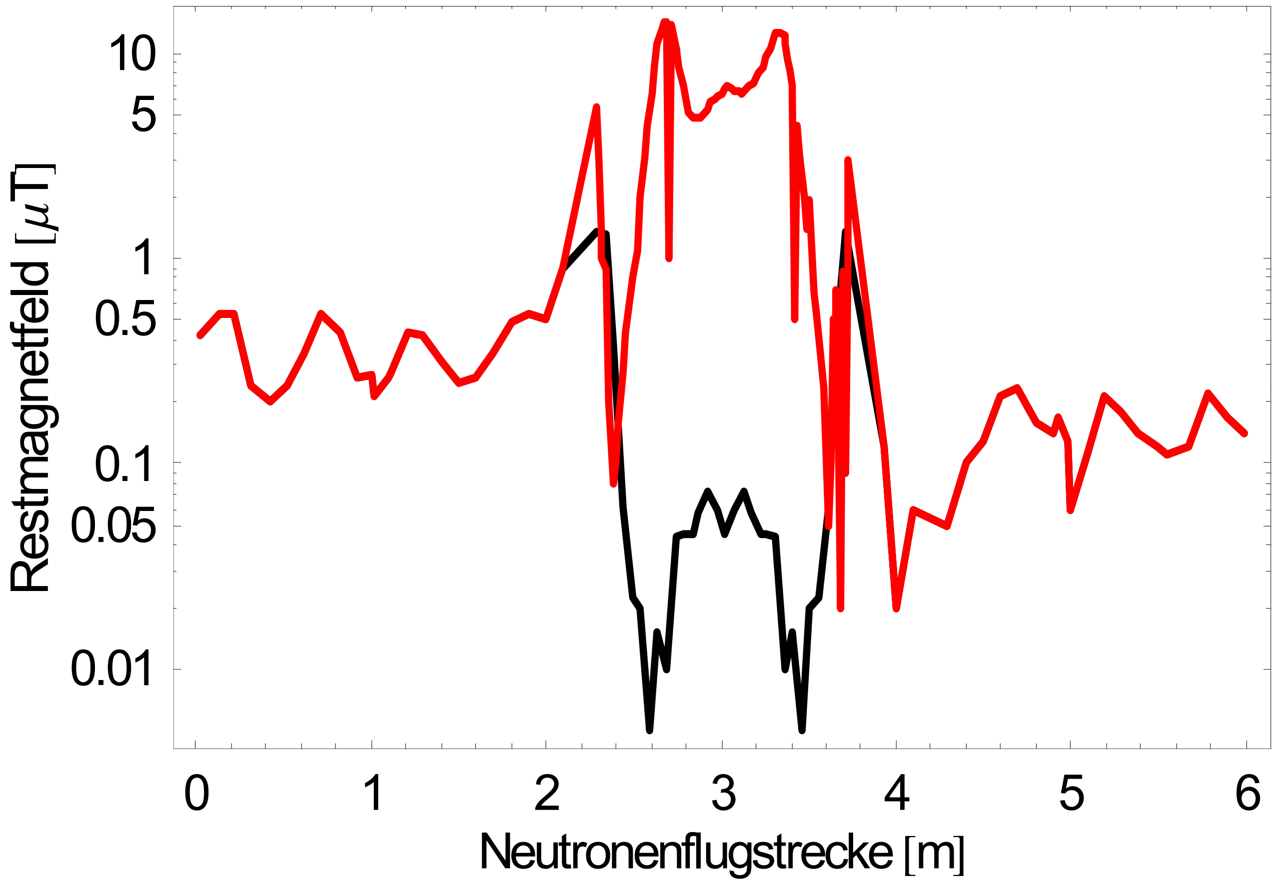
- (terrestrial) magnetic field shielding with double-walled μ-metal tube (length of spectrometer arms each 2.6 m)
- there is a coil in the μ -metal tube to switch on an external magnetic field

Residual magnetic field

Measuring of longitudinal and transversal residual magnetic field with 2 different sensors (Förster- and Barrington)

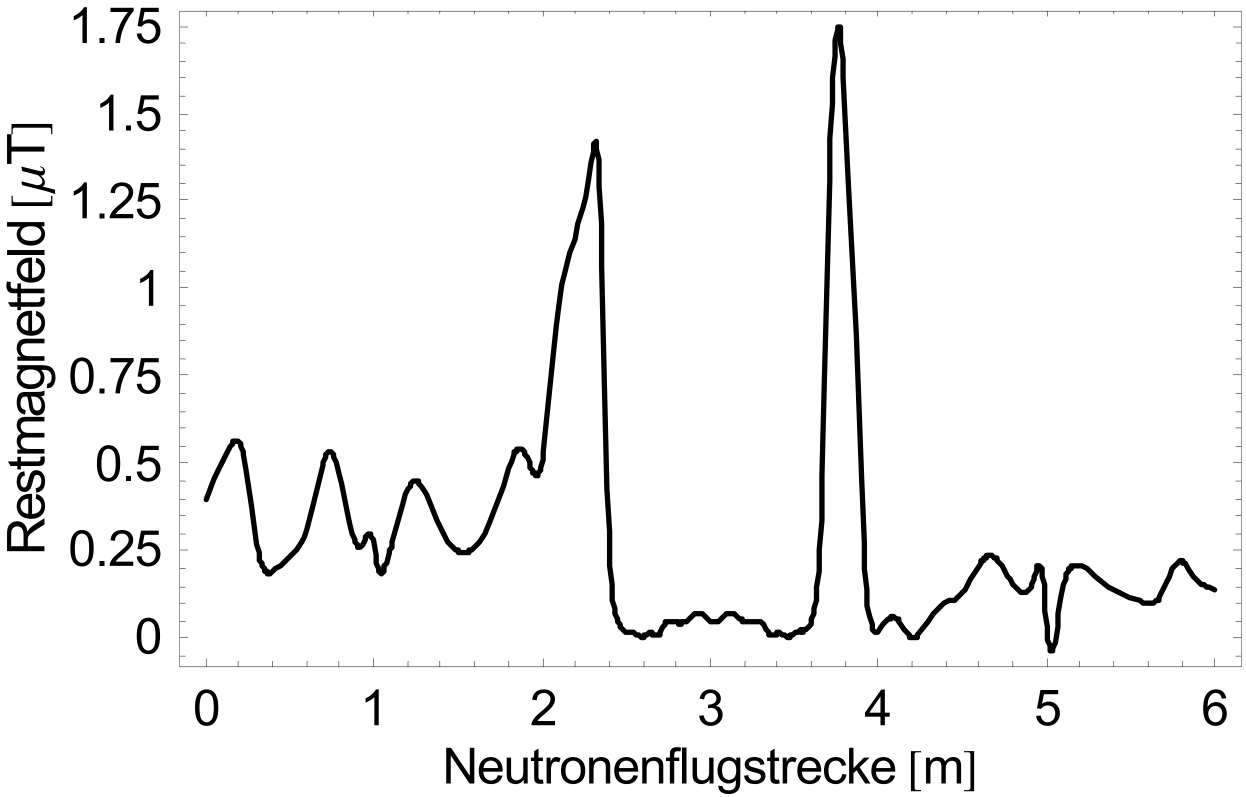
→ transversal: is negligible

→ longitudinal:



Residual magnetic field

the residual magnetic field with additional
μ -metal tube in the sample region:



Suppression integral

2 state system : neutron: |n>
mirror neutron: |n´>

Hamilton operator: $H = H_0 + \lambda \hbar \delta$

H_0: describes neutron and mirror neutron as 2 separated states without transition

$\hbar \delta$: perturbation, allowing a transition from n → n´

transition probability (measuring time << oscillation time):

$$P_{nn'}(t) = (\delta t)^2 \underbrace{\left[1 - \frac{4}{l^2} \int_0^{l} \int_0^{x''} \sin^2\left(\frac{\gamma}{2\mathrm{v}} \left(B_{\mathrm{int}}(x') - B_{\mathrm{int}}(x'') \right) \right) dx' dx'' \right]}_{\lambda}$$

- δ: nn´-transition amplitude
- l: length of trajectory
- v: neutron velocity
- γ: gyromagnetic ratio
- $B_{\mathrm{int}}(x'')$: B-field integral over trajectory

Evaluation

measured neutron flux without B-field $\hat{=}$ 1-$P_{nn'}$

measured neutron flux with B-field $\hat{=}$ 1

$$\frac{1-P_{nn'}}{1} = 1 \pm \Delta$$

with: $\Delta = \frac{1}{\sqrt{n}} \sqrt{\frac{\sum_i \left(x_i - \bar{x}\right)}{(n-1)}}$

$$\Rightarrow \quad (\delta t)^2 \, \lambda = \Delta$$

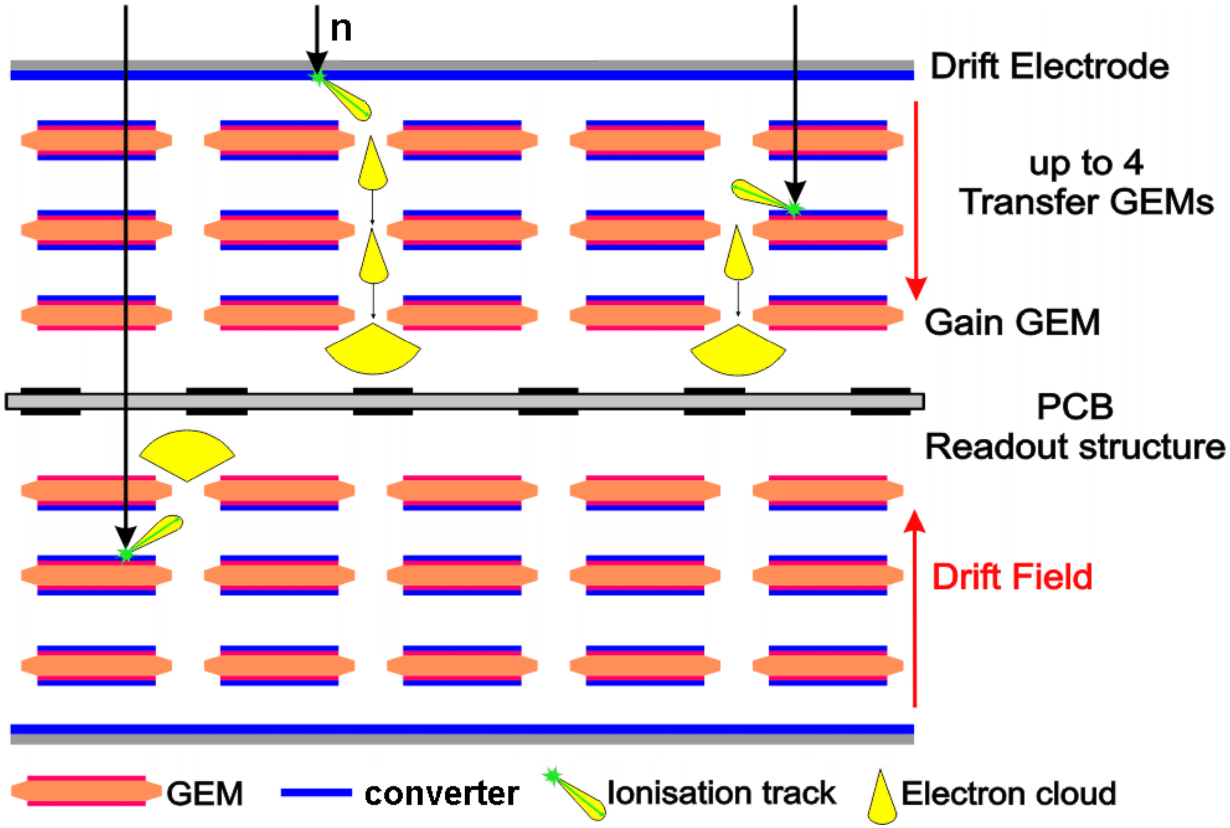
$$\tau_{\min} > \frac{l}{\mathrm{v}} \sqrt{\frac{\lambda}{\Delta}}$$

with: $\delta = \tau^{-1}$

Experiment-Detector

Detector: CASCADE-Detector

- measurement of high fluxes is possible
- high efficiency: for $\lambda = 11 \overset{o}{\mathrm{A}}$ → efficiency ca. 40 %



Results

suppression integral: $\lambda = 0.927$

without additional μ-metal tube: $\lambda = 0.35$

rate ratio: $\frac{\overline{N_{on}}}{N_{off}} = 1.000020(\underbrace{27}_{\Delta})$

Oscillation time: $\tau_{\min} > 2.72s$

90% confidence level

Reactor noise

$$\text{standard deviation} = \sqrt{(\text{statistical error})^2 + (\text{reactor noise})^2}$$

statistical error and reactor noise are not correlated

$$\left.\begin{array}{ll} \text{statistical error:} & 0.0039 \\ \text{reactor noise:} & 0.0072 \end{array}\right\} \quad \text{standard deviation : } 0.0082$$

Outlook

Measurement with VCNs

→ larger neutron time of flight
→ larger observation time

⇓

The probability to observe a
neutron-mirror neutron-oscillation increases

But an additional monitoring of the reactor
noise is necessary

Thank you for your attention

Reactor noise

Reactor noise versus correlation time: