Fundamental interactions: The electron as probe of new physics
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The electron's electric dipole moment (eEDM)
New Nikhef research program since 2016
Funded as program by NWO for 2017-2023

Scientific staff:
- Anastasia Borschevsky
- Rick Bethlem
- Steven Hoekstra
- Klaus Jungmann
- Rob Timmermans
- Wim Ubachs
- Lorenz Willmann

PhD students:
- Parul Aggarwal
- Kevin Esajas
- Pi Haasse
- Yongliang Hao
- Thomas Meijknecht
- Maarten Mooij
- Artem Zapara

Postdocs
- Malika Denis

Technical staff:
- Oliver Böll
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Master students:
- Jeroen Maat
- Janna de Wit
- Diewertje Doeglas

Bachelor students
- Mark Buisman
- Rutget Hof
- Jeroen Muller
- Hidde Makaske
- Kees Steinebach
- Pieter van Vliet
- Cornelis Zandt

Starting in 2018:
- PhD students (2)
- Postdocs (1-2)
- Master students (3)
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The Electric Dipole Moment of the electron (eEDM)

‘Is the electron round?’

eEDM violates P, T and CP symmetry (provided CPT holds)
The Standard Model

Probing physics at high energies: $3 \times 10^{30} = 30$ TeV

Next-generation experiment
How to measure a dipole moment?

However, also magnetic dipole moment (and charge!)

Solution: use electron embedded in a polar molecule!

We have selected BaF
Energy level structure of the BaF molecule

Electronically excited state

\( \Lambda^2 \Pi_{1/2} \)

\( \Delta^2 \Delta \)

Vibrational ground state

Electronic ground state
Energy level structure of the BaF molecule

-1 0 +1
\( m_F \)

\( F=1 \)  
\( \sim 65 \text{ MHz} \)

\( F=0 \)

\( \sim 15 \text{ GHz} \)

\( v''=0 \)

Vibrational ground state has rotational substructure

Adding \( l=1/2 \) -> hyperfine structure:

Field free

Electric field

\( -d_e E_{eff} \)

Magnetic field

\( \mu_B B \)
How to read out small energy shifts:
spin interferometer

Molecular beam

initialise
$|F, m_F\rangle = |0, 0\rangle$

split
$\frac{1}{\sqrt{2}}(|1, -1\rangle + |1, 1\rangle)$

evolve
$\phi = (\pm d_e E_{\text{eff}} \mp \mu_B B) T/\hbar$

recombine
$\frac{1}{\sqrt{2}}(e^{i\phi} + e^{-i\phi})$

readout
$F = 0 \propto \cos^2(\phi)$
Interferometer phase $\phi = (\pm d_e E_{eff} \mp \mu_B B) T / \hbar$
Increasing the eEDM sensitivity

Measure energy shift that correlates with electric field direction reversal

\[ \sigma_d = \frac{\hbar}{e} \frac{1}{2E_{\text{eff}} \tau \sqrt{N}} \]

statistical error:

- Effective electric field
- Applied electric field (kV/cm)
- Number of detected molecules
- Coherent interaction time
- Cold Molecules
- Polar molecule
Cold molecules:

Combining three recent experimental breakthroughs

1) Cryogenic source
2) Stark deceleration - Dutch invention!
3) Molecular laser cooling - a new opportunity

Using BaF molecules, we can create a very **intense, slow and cold** beam
Current status:

Team is formed
First results form theory obtained
Experiment under construction

4.5 m long molecule decelerator @ VSI
Built with great effort of KVI-CART workshop
Traveling-wave decelerator
Traveling-wave decelerator - operating principle

Allows us to create intense molecular beam
Temperature ~ 10 mK, forward velocity ~ 30 m/s
Cold Molecules Lab - eEDM data-taking planned in 3 years from now
Young and active research community

12-17 June 2107, eEDM program kickoff meeting and international summerschool, Ameland
“Low-energy precision measurements of physics beyond the standard model”
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