Transmission measurements at the KATRIN main spectrometer

Stefan Groh
GK-Workshop Bad Liebenzell, October 2013
Outline

- How does KATRIN work
- Commissioning of spectrometer and detector
- Alignment of eGun and Detector
- Transmission function measurement
- Radial potential scan
- Transmission function at high rate
Outline

- How does KATRIN work
- Commissioning of spectrometer and detector
- Alignment of eGun and Detector
- Transmission function measurement
- Radial potential scan
- Transmission function at high rate

Model independent measurement of the neutrino mass with a sensitivity of 200 meV (90% C.L.)
Neutrino mass takes away energy that changes shape of electron spectrum.

Precise spectroscopy of beta decay electrons necessary.
Experimental Setup

How to measure the energy of the electrons?

Source
Transport
Spectrometers + detector
Why the big spectrometer?

Source: isotropic e⁻ emission

Cyclotron motion along field line

Fixed polar angle between p and B

Electric field only filters long. comp.

Problem: How to filter the electrons according to their kinetic energy?

Solution: Decrease the polar angle of the electrons at the analyzing point

\[ E_{\text{kin}} = E_{\parallel} + E_{\perp} \]

\[ \mu = \frac{E_{\perp}}{B} \]

\( E_{\perp} \rightarrow E_{\parallel} \)

\( \mu \) is conserved in an adiabatic motion

reduce magnetic field at the analyzing point
The MAC-E-Filter principle

- **Electrode**
- **Solenoid**
- **Source**
- **B\text{\textsubscript{s}}**
- **U\text{\textsubscript{s}}**
- **B\text{\textsubscript{min}}**
- **U\text{\textsubscript{0}}**
- **B\text{\textsubscript{max}}**
The energy resolution

ret. potential: 18000 V

electron energy: 17999.9 eV
The energy resolution

electron energy: 18000.5 eV

ret. potential: 18000 V
The energy resolution

ret. potential: 18000 V

electron energy: 18001.0 eV

\[ E_{\text{start}} - qU_0 \]
The transmission function

\[ \Delta E = 18.6 \text{ keV} \cdot \frac{B_{\text{min}}}{B_{\text{max}}} \approx 1 \text{ eV} \]
Integral spectrum

\[ N(qU) \approx \int_0^{E_0} \frac{dN}{dE} (E_0, mv^2) \times T(E, qU) dE \]

Integral spectrum is convolution of differential spectrum with transmission function
Precise knowledge and detailed understanding of the transmission function is essential for a successful neutrino mass measurement.
Outline

- How does KATRIN work
- Commissioning of spectrometer and detector
- Alignment of eGun and Detector
- Transmission function measurement
- Radial potential scan
- Transmission function at high rate

Measurement phase finished last week
Commissioning of Spectrometer and Detector

Main goals:
- Test of Hardware and Slowcontrol components
- Measurement and Understanding of background
- Understanding of transmission properties
- Verification of simulations software and models
Focal plane detector system

Si-PIN Diode with 148 Pixel

See talk by J. Schwarz, later today
Electron Gun:
- Quasi monoenergetic
- Pulsed for ToF measurements
- Movable to cover full detector flux
Outline

- How does KATRIN work
- Commissioning of spectrometer and detector
- Alignment of eGun and Detector
- Transmission function measurement
- Radial potential scan
- Transmission function at high rate
Flux tube - eGun

Z-Y-Plane

y in m

z in m

-16 -15 -14 -13 -12 -11 -10

0 0.5 1

-0.5

0 0.5 1

-16 -15 -14 -13 -12 -11 -10
Flux tube

Z-Y-Plane

main spectrometer

eGun
detector
Detailed understanding of field lines is very important.
Misalignment of eGun and detector needs to be taken into account in the analysis

\[ \Delta x = -3.28 \text{ mm} \]
\[ \Delta y = -3.34 \text{ mm} \]
horiz. Winkel: \(-1.01^\circ\)
vert. Winkel: \(-0.82^\circ\)
Different magnetic coil setup

Z-Y-Plane

y in m

z in m

-15 -10 -5 0 5 10 15
Different magnetic coil setup

Event Count

Ereignisse

$\Delta x = -3.34 \text{ mm}$
$\Delta y = -9.93 \text{ mm}$
horiz. Winkel $1.23^\circ$
vert. Winkel $-0.89^\circ$
Comparison with simulation

Measurement

Simulation

Event Count

Ereignisse

10^5

10^4

10^3

10^2

10

1
Comparison with simulation

Field lines for different settings can be very good reproduced by simulations

plots by N. Stallkamp
Outline

- How does KATRIN work
- Commissioning of spectrometer and detector
- Alignment of eGun and Detector
- Transmission function measurement
- Radial potential scan
- Transmission function at high rate
Transmission function

Spectrometer works as MAC-E-Filter – commissioning successful
Outline

- How does KATRIN work
- Commissioning of spectrometer and detector
- Alignment of eGun and Detector
- Transmission function measurement
- Radial potential scan
- Transmission function at high rate
Measure TF at different radii

Detected distribution

-0.04 -0.03 -0.02 -0.01 0 0.01 0.02 0.03 0.04

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Radial transmission scan

Z-X-Plane

transmission probability

$U_{IE} - U_{eGun}$

$z$ in m
Radial transmission scan

Z-X-Plane

transmission probability

$U_{IE} - U_{eGun}$

$z$ in m

$x$ in m

0  5  10  15

0  0.2  0.4  0.6  0.8  1  1.2

Radial transmission scan

Stefan Groh – Transmission measurements at the KATRIN main spectrometer
2.10.2013
Radial transmission scan

Z-X-Plane

transmission probability

$U_{IE} - U_{eGun}$

$z$ in m

$x$ in m
Radial transmission scan

Z-X-Plane

transmission probability

\( U_{IE} - U_{eGun} \)
Radial potential measurement

Preliminary

![Graph showing relative potential penetration vs. x in m]
Outline

- How does KATRIN work
- Commissioning of spectrometer and detector
- Alignment of eGun and Detector
- Transmission function measurement
- Radial potential scan
- Transmission function at high rate
Detector efficiency at high rates

Efficiency of detector depends on rate and time profile
Transit flight times at different transmission points

$\Delta t \approx 40 \mu s$
Transit flight times at different transmission points

monte carlo

$\Delta t \approx 20 \mu s$
Transit flight times at different transmission points

\[ \Delta t \approx 5 \mu s \]
Influence on transmission function

Transmission functions can only be measured at low rate (<5 kcps)
TF Measurement at high rate

Predicted high rate effect could also be measured

Upgrade of the detector electronics is already planned
Conclusion

- KATRIN uses the MAC-E-Filter technique to measure an integrated electron spectrum
- Detailed knowledge of transmission function is important for neutrino mass analysis
- Successful commissioning of the spectrometer and detector section
- Electron gun can be used for transmission function measurements and potential mapping
- Predicted “high rate”-effects of the transmission function could be confirmed by measurements
Open questions?

What tool does he use to track particles in that low energy regime?

What's for lunch today?

zZzZzZ
BACKUP SLIDES
Kassiopeia

- KATRIN's main particle tracking framework
- Modern C++ design
- Field solvers for electric and magnetic fields
- Particle generators
- Multiple tracking routines
- Multiple Interaction routines
- Visualization
- Easy configurable via xml files
- Interface to measurement parameters
- Full modular
- Also used by other experiments
KEMField

- Standard Field Solver for Kassiopeia (E and B)
- Very detailed model of the main spectrometer
- > 4 Million Elements
- Employs MPI and OpenCL

T.J. Corona
Main spectrometer
Detector
Detector
MORE BACKUP SLIDES
Chicken with pepper and rice and red fruit jelly for dessert