

Contents

1	Preamble	1
2	Introduction to Neutrino Physics	3
2.1	The Discovery of the Neutrino	4
2.1.1	Postulation of the Neutrino by Pauli	4
2.1.2	First Detection of a Neutrino	5
2.1.3	Discovery of ν_μ and ν_τ	6
2.2	Neutrino Oscillations	6
2.2.1	First Discovery	7
2.2.2	Theoretical Description	8
2.2.3	Determination of Oscillation Parameters	11
2.2.4	Oscillation in Matter	12
2.3	Theory of Neutrino Mass	13
2.3.1	Possible Mass Terms in the Lagrangian	14
2.3.2	See Saw Mechanism	16
2.4	Determination of the Neutrino Mass	17
2.4.1	Cosmology	17
2.4.2	Neutrinoless Double Beta Decay	20
2.4.3	Single Beta Decay	23
	References	25
3	Introduction to the KATRIN Experiment	29
3.1	Experimental Overview	29
3.1.1	Tritium Source	30
3.1.2	Transport Section	31
3.1.3	Spectrometer Section	34
3.1.4	Focal Plane Detector	37
3.2	MAC-E-Filter Principle	39
3.2.1	The Transmission Function	42
3.2.2	The Response Function	44
3.3	Systematic and Statistical Uncertainties	45
3.3.1	Sources of Systematic Errors	45

3.3.2	Sensitivity of KATRIN	48
3.4	Overview of Background Sources at KATRIN	48
3.4.1	Importance of Low Background for KATRIN	49
3.4.2	Detector Background	50
3.4.3	Spectrometer Background	50
3.4.4	Countermeasures for Background	53
	References	53
4	Monte Carlo Simulation Package	55
4.1	Purpose of Kassiopeia	55
4.1.1	Optimization of Electromagnetic Design	56
4.1.2	Monte Carlo Simulations	56
4.1.3	Investigation of Systematic Effects and Statistical Uncertainty of KATRIN	56
4.2	General Organization	57
4.2.1	Representation of Physical States	57
4.2.2	Evolution of Physical States	59
4.3	Overview of Physical Modules	60
4.3.1	Particle Creation	60
4.3.2	Particle Tracking (KTrack).	62
4.3.3	Field Calculation Methods	67
4.3.4	Particle Detection (KESS)	71
4.3.5	Source Spectrum Calculation	71
4.4	User Interface	72
4.4.1	Toolbox Configuration.	72
4.4.2	Instruction Configuration	73
4.5	Output	74
	References	74
5	Muon Induced Background	77
5.1	Electric and Magnetic Shielding	77
5.2	Circumvention of Shielding and Background Production Mechanism	79
5.3	Sources of Non-axially Symmetric Magnetic Fields	80
5.3.1	Magnetic Materials	81
5.3.2	Deformation of Air Coil System	83
5.3.3	Resulting Radial Drift Velocities	85
5.4	Conclusion	87
	References	88
6	Background Due to Penning Traps	89
6.1	Model of Background Production Mechanism	89
6.1.1	Penning Trap Filling Mechanism	90
6.1.2	Background Production	91

6.2	Small Penning Trap at the Pre-spectrometer	92
6.2.1	Overview of Measurement Series	92
6.2.2	Penning Trap Induced Background via Photons	95
6.3	Conclusion	100
	References	101
7	Background Due to Stored Electrons Following	
	Nuclear Decays	103
7.1	Model of the Background Production Mechanism	103
7.2	Radon Model to Explain Observations at Pre-spectrometer.	105
7.2.1	Emanation of Radon	106
7.2.2	Electron Creation by Radon Decay	107
7.2.3	Validation of Radon Model	110
7.3	Expected Background Rate at the Main Spectrometer	116
7.3.1	Stored Electrons in the Main Spectrometer	117
7.3.2	Background Rate Due to Single Tritium β - and Radon α -Decays	120
7.3.3	Estimation of Nuclear Tritium and Radon Decay Rates in the Main Spectrometer	122
7.3.4	Estimation of Total Background Rate	129
7.4	Impact of the Background on the Neutrino Mass Sensitivity of KATRIN	130
7.5	Conclusion	134
	References	135
8	Active Background Reduction with Electron	
	Cyclotron Resonance	137
8.1	ECR and its Applications in Physics	138
8.2	The Working Principle of ECR at a KATRIN Spectrometer	138
8.3	Proof of Principle at the KATRIN Pre-Spectrometer	139
8.3.1	Experimental Setup	139
8.3.2	Measurement Results.	145
8.4	Expected Background Reduction at the Main Spectrometer	148
8.4.1	Optimizing the Frequency Settings	149
8.4.2	Optimizing the Amplitude of the HF Field.	152
8.4.3	Effect of an HF Field on Electrons of Different Energies.	153
8.5	Conclusion	155
	References	155
9	Conclusion.	157

Appendix A. 161

Appendix B. 169

Appendix C. 175

Appendix D. 179

Appendix E. 181

Appendix F. 187

Appendix G 189

Curriculum Vitae 193

Background Processes in the Electrostatic
Spectrometers of the KATRIN Experiment

Mertens, S.

2014, XVI, 196 p. 116 illus., 108 illus. in color.,
Hardcover

ISBN: 978-3-319-01176-9