

# Contents

<b>1. Introduction</b>	<b>9</b>
<b>2. Neutrino oscillations</b>	<b>13</b>
2.1. Three-flavour oscillations . . . . .	15
2.2. Sterile neutrinos . . . . .	19
2.3. Neutrino masses . . . . .	20
2.4. Oscillations between active and sterile neutrino states . . . . .	23
2.4.1. Hints for eV-scale sterile neutrinos . . . . .	29
2.5. Constraints on eV-scale sterile neutrino from global fits . . . . .	33
2.6. Constraints on the elements of neutrino mixing matrix . . . . .	41
<b>3. Search for <math>\nu_\tau</math> interactions – experimental methods and results</b>	<b>45</b>
3.1. Tau neutrino . . . . .	45
3.2. Summary of experimental results concerning $\nu_\tau$ interactions . . . . .	49
<b>4. Search for <math>\nu_\tau</math> in the MINOS+ experiment</b>	<b>59</b>
4.1. Neutrino beam . . . . .	59
4.2. Beam flux simulation . . . . .	61
4.3. Detectors . . . . .	64
4.4. Event analysis methods . . . . .	65
4.4.1. Standard reconstruction . . . . .	66
4.4.2. Reconstruction in three dimensions . . . . .	66
4.4.3. Hough transform . . . . .	68
4.4.4. $k$ NN selection . . . . .	69
4.5. $\nu_\tau$ selection . . . . .	69
4.5.1. Preselection . . . . .	69
4.5.2. Selection . . . . .	72
<b>5. Search for sterile neutrinos in the MINOS and MINOS+ experiments</b>	<b>74</b>
5.1. Setting limits . . . . .	74
5.1.1. Neyman method . . . . .	74
5.1.2. Feldman–Cousins method . . . . .	75
5.1.3. Profile likelihood method . . . . .	75
5.1.4. Raster and Global Scan . . . . .	76
5.2. Systematic uncertainties . . . . .	77
5.3. Study of NC events . . . . .	78
5.4. Fit to Far/Near ratio in the 3+1 oscillation model . . . . .	79
5.5. Two-detector Fit in the 3+1 oscillation model . . . . .	81
5.6. Limits on 3+1 model from search of $\nu_\tau$ appearance . . . . .	83

<b>6. Summary and conclusions</b>	<b>88</b>
<b>7. Acknowledgments</b>	<b>90</b>
<b>A. Oscillation parameters from global fit</b>	<b>91</b>
<b>B. Profile likelihood method</b>	<b>92</b>
<b>Bibliography</b>	<b>94</b>