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# 1 Lebenslauf

## *Persönliche Daten*



Akademischer Titel: Dipl.-Ing. Dr. techn.

Adresse: 1130 Vienne, Steinklammerg.19

Ort/Datum Geburt: Vienna, 18.06.1977

Zivildienst: June 2005 - June 2006, Vienna

Familienstand: verheiratet

Nationalität: Österreich

Email: sponar@tuwien.ac.at and stephan.sponar@gmx.net

Web: [www.neutroninterferometry.com](http://www.neutroninterferometry.com)

Arbeitgeber: TU Wien; Atominstitut, Stadionallee 2, 1020 Wien

ORCID: <https://orcid.org/0000-0002-6568-6045>

## **Ausbildung**

März 2011	Rigorosum (Dr. techn.) mit Auszeichnung Titel: <i>Multi-Entanglement in Neutron Interferometric and Polarimetric Experiments</i> , Betreuer: Prof. Yuji Hasegawa
Juli 2006 - März 2011	Doktorarbeit am Atominstitut, TU-Wien, Doktorandenstelle finanziert über FWF Mittel
Jänner 2005	Diplomprüfung (Dipl.-Ing.) Technische Physik, TU-Wien Titel: <i>Non-cyclic geometric phases in neutron polarimetric experiments</i> (Betreuer: Prof. Gerald Badurek)
Sept. 1995 - Jän. 2005	Physikstudium an der TU-Wien
1987-1995	Realgymnasium, Rosasg., 1120 Wien (Matura: Mai 1995)

## **Sprachkenntnis:**

Deutsch, Englisch, Französisch (Basiswissen)

**Arbeitserfahrung**

Jänner 2016 - andauernd	Senior-Scientist Position, TU-Wien Atominstitut, Neutron and Quantum Physics Group
Nov. 2011 - Jan. 2016	Post Doc, TU-Wien Atominstitut, Neutron and Quantum Physics Group
Mai 2006 - March 2011	Forschungsaufenthalte Institute Laue Langevin (ILL) Grenoble, France

**Lehre**

Ue Grundlagen der Physik Ia, Ue Grundlagen der Physik Ib, Ue Grundlagen der Physik II, Ue Grundlagen der Physik III, Physik Proseminar II, Quantenphysik, Praktikum aus Neutronenphysik

(eine detaillierte Auflistung aller Lehrveranstaltungen findet sich in Kapitel 6)

**Forschungsprojekte**

- *Weak Measurements, Phases and Entanglement in Neutron Optics*  
FWF P 24973: Jan. 2013 - Dez. 2016
- *Weak Measurements and Uncertainty Relations in Neutron Optics*  
FWF P 30677: Jan. 2018, andauernd

(Details zu den Projekten sind in Kapitel 4 zu finden)

## 2 Publikationsliste

### Top 5 Publikationen:

- I. T. Denkmayr, H. Geppert, H. Lemmel, M. Waegell, J. Dressel, Y. Hasegawa, and St. Sponar, *Experimental demonstration of direct path state characterization by strongly measuring weak values in a matter-wave interferometer*, Physical Review Letters **118**, 010402 (2017) [quant-ph/1604.04102].
- II. G. Sulyok and St. Sponar, *Is Heisenberg's error-disturbance uncertainty relation violated?: Experimental study of competing approaches*, Physical Review A **96**, 022137 (2017)
- III. St. Sponar, T. Denkmayr, H. Geppert, H. Lemmel, A. Matzkin, J. Tollaksen, and Y. Hasegawa, *Weak values obtained in matter-wave interferometry*, Physical Review A **92**, 062121 (2015) [quant-ph/1404.2125].
- IV. T. Denkmayr, H. Geppert, St. Sponar, H. Lemmel, A. Matzkin, J. Tollaksen, and Y. Hasegawa, *Observation of a quantum Cheshire Cat in a matter-wave interferometer experiment*, Nature Communications **5**, 4492 (2014) **OPEN**.
- V. J. Erhart, St. Sponar, G. Sulyok, G. Badurek, M. Ozawa, and Y. Hasegawa, *Experimental demonstration of a universally valid error-disturbance uncertainty relation in spin-measurements*, Nature Physics **8**, 185-189 (2012) [quant-ph/1201.1833].

### Publikationen in Begutachtung:

- i) St. Sponar, Armin Danner, Kazuma Obigane, Simon Hack, and Yuji Hasegawa, *Experimental test of tight state-independent preparation uncertainty relations for qubits*, submitted to *Phys. Rev. Lett.* (Feb 2020).

### Publikationen (peer-reviewed):

39. A. Danner, B. Demirel, W. Kersten, R. Wagner, H. Lemmel, St. Sponar and Y. Hasegawa, *Spin-rotation coupling observed in neutron interferometry*, npj Quantum Information **6**, 23 (2020).
38. Bülent Demirel, St. Sponar, and Yuji Hasegawa, *Measurements of Entropic Uncertainty Relations in Neutron Optics*, Applied Science **10**, 1087 (2020).
37. R. Wagner, L. Brandl, W. Kersten, St. Sponar, Y. Hasegawa, C. Huber, F. Bruckner and D. Suess, *3D printed magnets for neutron spin manipulation*, EPJ Web Conf. **219**, 10008 (2019).

36. W. Kersten, L. Brandl, R. Wagner, C. Huber, F. Bruckner, Y. Hasegawa, D. Suess, and St. Sponar, *Additive-Manufactured and Topology-Optimized Permanent Magnet Spin Rotator for Neutron Interferometry*, Physical Review Applied **12**, 014023 (2019).
35. A. Danner, B. Demirel, St. Sponar, and Y. Hasegawa, *Development and performance of a miniaturised spin rotator suitable for neutron interferometer experiments*, Journal of Physics Communications **3**, 035001 (2019).
34. B. Demirel, St. Sponar, A. A. Abbott, C. Branciard, and Y. Hasegawa, *Experimental test of an entropic measurement uncertainty relation for arbitrary qubit observables*, New Journal of Physics **21**, 013038 (2019).
33. M. Blackener, B. Demirel, I. Drevensek-Olenik, M. Fally, P. Flauger, P. Geltenbort, Y. Hasegawa, R. Kurinjimala, M. Lioen, C. Pruner, St. Sponar, Y. Tomita, J. Klepp, *Monte-Carlo simulation of neutron transmission through nanocomposite materials for neutron-optics applications*, Nuclear Instruments and Methods in Physics Research A **916**, 154–157 (2019).
32. H. Geppert-Kleinrath, T. Denkmayr, St. Sponar, H. Lemmel, T. Jenke, and Y. Hasegawa, *Multifold paths of neutrons in the three-beam interferometer detected by a tiny energy kick*, Physical Review A **97**, 052111 (2018).
31. T. Denkmayr, J. Dressel, H. Geppert-Kleinrath, Y. Hasegawa, and St. Sponar, *Weak values from strong interactions in neutron interferometry*, Physica B **551**, 339-346 (2018).
30. M. Waegell, T. Denkmayr, H. Geppert, D. Ebner, T. Jenke, Y. Hasegawa, St. Sponar, J. Dressel, and J. Tollaksen, *Confined Contextuality in Neutron Interferometry: Observing the Quantum Pigeonhole Effect*, Physical Review A **96**, 052131 (2017) [quant-ph/1609.06046].
29. G. Sulyok and St. Sponar, *Is Heisenberg's error-disturbance uncertainty relation violated?: Experimental study of competing approaches*, Physical Review A **96**, 022137 (2017).
28. T. Denkmayr, H. Geppert, H. Lemmel, M. Waegell, J. Dressel, Y. Hasegawa, and St. Sponar, *Experimental demonstration of direct path state characterization by strongly measuring weak values in a matter-wave interferometer*, Physical Review Letters **118**, 010402 (2017) [quant-ph/1604.04102].
27. B. Demirel, St. Sponar, G. Sulyok, M. Ozawa, and Y. Hasegawa, *Residual error-disturbance uncertainties in successive spin- $1/2$  measurements tested in matter-wave optics*, Physical Review Letters **117**, 140402 (2016) [quant-ph/1511.03462].
26. St. Sponar, *Error-disturbance uncertainty relations in neutron spin measurements*, International Journal of Quantum Information **14**, 1640016 (2016).

25. St. Sponar, T. Denkmayr, H. Geppert, and Y. Hasegawa, *Fundamental Features of Quantum Dynamics Studied in Matter-Wave Interferometry—Spin Weak Values and the Quantum Cheshire-Cat*, *Atoms* **4**, 11 (2016). **OPEN**
24. St. Sponar, T. Denkmayr, H. Geppert, H. Lemmel, A. Matzkin, J. Tollaksen, and Y. Hasegawa, *Weak values obtained in matter-wave interferometry*, *Physical Review A* **92**, 062121 (2015) [quant-ph/1404.2125].
23. G. Sulyok, St. Sponar, B. Demirel, F. Buscemi, M.J. Hall, M. Ozawa, and Y. Hasegawa, *Experimental test of entropic noise-disturbance uncertainty relations for spin -  $1/2$  measurements*, *Physical Review Letters* **115**, 030401 (2015) [quant-ph/1504.04200].
22. B. Demirel, St. Sponar, and Y. Hasegawa, *Measurement of the spin-rotation coupling in neutron polarimetry*, *New Journal of Physics* **17**, 023065 (2015).
21. St. Sponar, G. Sulyok, J. Erhart, and Y. Hasegawa, *Error-Disturbance Uncertainty Relations in Neutron-Spin Measurements*, *Advances in High Energy Physics* **2014**, 735398 (2014).
20. T. Denkmayr, H. Geppert, St. Sponar, H. Lemmel, A. Matzkin, J. Tollaksen, and Y. Hasegawa, *Observation of a quantum Cheshire Cat in a matter-wave interferometer experiment*, *Nature Communications* **5**, 4492 (2014) **OPEN**.
19. J. Klepp, St. Sponar, and Y. Hasegawa, *Fundamental phenomena of quantum mechanics explored with neutron interferometers*, *Progress of Theoretical and Experimental Physics* **2014**, 082A0 (2014) [quant-ph/1407.2526].
18. H. Geppert, T. Denkmayr, St. Sponar, H. Lemmel, and Y. Hasegawa, *Improvement of the polarized neutron interferometer setup demonstrating violation of a Bell-like inequality*, *Nuclear Instruments and Methods in Physics Research A* **763**, 417–423 (2014) [quant-ph/1404.3512].
17. G. Sulyok, St. Sponar, J. Erhart, G.Badurek, M. Ozawa, and Y. Hasegawa, *Violation of Heisenberg’s error-disturbance uncertainty relation in spin measurements*, *Physical Review A* **88**, 022110 (2013) [quant-ph/1305.7251].
16. St. Sponar, J. Klepp, K. Durstberger-Rennhofer, H. Geppert, M. Both, C. S. Schmitzer, H. Bartosik, G. Badurek, and Y. Hasegawa, *High-efficiency manipulations of triply entangled states in neutron polarimetry*, *New Journal of Physics* **14**, 053032 (2012).
15. J. Erhart, St. Sponar, G.Sulyok, G.Badurek, M. Ozawa, and Y. Hasegawa, *Experimental demonstration of a universally valid error-disturbance uncertainty relation in spin-measurements*, *Nature Physics* **8**, 185-189 (2012) [quant-ph/1201.1833].
14. Y. Hasegawa, C. Schmitzer, H. Bartosik, J. Klepp, St. Sponar, K. Durstberger-Rennhofer, and G. Badurek, *Falsification of Leggett’s model using neutron matter-waves*, *New Journal of Physics* **14**, 023039 (2012).

13. St. Sponar, J. Klepp, R. Loidl, S. Filipp, K. Durstberger, R. Bertlmann, G. Badurek, H. Rauch, and Y. Hasegawa, *Geometric phase in entangled systems: A single-neutron interferometer experiment*, Physical Review A **81**, 042113 (2010) [quant-ph/0907.4909].
12. St. Sponar, J. Klepp, K. Durstberger, R. Loidl, S. Filipp, M. Lettner, R. Bertlmann, G. Badurek, H. Rauch, and Y. Hasegawa, *New aspects of geometric phases in experiments with polarized neutrons*, Journal of Physics A: Mathematical and Theoretical **43**, 354015 (2010).
11. St. Sponar, J. Klepp, C. Zeiner, G. Badurek, and Y. Hasegawa, *Violation of a Bell-like inequality for spin-energy entanglement in neutron polarimetry*, Physics Letters A **374**, 431-434 (2010) [quant-ph/0907.4654].
10. Y. Hasegawa, R. Loidl, G. Badurek, K. Durstberger, St. Sponar, and H. Rauch, *Engineering of triply entangled states in a single-neutron system*, Physical Review A **81**, 032121 (2010).
9. Y. Hasegawa, K. Durstberger, St. Sponar, and H. Rauch, *Kochen-Specker theorem studied with neutron interferometer*, Nuclear Instruments and Methods in Physics Research A **634**, 21-24 (2010).
8. H. Bartosik, J. Klepp, C. Schmitzer, St. Sponar, A. Cabello, H. Rauch, and Y. Hasegawa, *Experimental test of quantum contextuality in neutron interferometry*, Physical Review Letters **103**, 040403 (2009) [quant-ph/0904.4576].
7. Y. Hasegawa, G. Badurek, S. Filipp, J. Klepp, R. Loidl, St. Sponar, and H. Rauch, *Entanglement between degrees of freedom of single-neutrons*, Nuclear Instruments and Methods in Physics Research A **611**, 310-313 (2009).
6. St. Sponar J. Klepp, R. Loidl, S. Filipp, G. Badurek, Y. Hasegawa, and H. Rauch, *Coherent energy manipulation in single-neutron interferometry*, Physical Review A **78**, 061604(R) (2008) [quant-ph/0803.3545].
5. St. Sponar, J. Klepp, G. Badurek, and Y. Hasegawa, *Zero-field and Larmor spinor precessions in a neutron polarimeter experiment*, Physics Letters A **372**, 3153-3156 (2008) [quant-ph/0802.1411].
4. J. Klepp, St. Sponar, S. Filipp, M. Lettner, G. Badurek, and Y. Hasegawa, *Observation of Nonadditive Mixed-State Phases with Polarized Neutrons*, Physical Review Letters **101**, 150404 (2008) [quant-ph/0809.0572].
3. St. Sponar, J. Klepp, Y. Hasegawa, E. Jericha, and G. Badurek, *Non-Cyclic Geometric Phases in Mixed State Neutron Polarimetry*, Acta Physica Hungarica B **26**, 165-171 (2006).
2. J. Klepp, St. Sponar, Y. Hasegawa, E. Jericha, and G. Badurek, *Noncyclic Pancharatnam phase for mixed state  $SU(2)$  evolution in neutron polarimetry*, Physics Letters A **342**, 48 - 52 (2005) [quant-ph/0505209].

1. M. Zehetmayer, M. Eisterer, St. Sponar, H. W. Weber, A. Wisniewski, R. Puzniak, P. Panta, J. Karpinski, *Magnetic properties of superconducting  $HgBa_2CuO_{4+d}$  single crystals in the overdoped state before and after particle irradiation*, Physica C **418**, 73 - 86 (2005).

### Beiträge in Tagungsbänden:

1. St. Sponar, H. Geppert, T. Denkmayr, H. Lemmel and Y. Hasegawa, *Asking Neutrons where they have been*, J. Phys.: Conf. Ser. 1316 012002 (2019).
2. St. Sponar, J. Klepp, C. Schmitzer, H. Bartosik, K. Durstberger-Renhofer, G. Badurek, and Y. Hasegawa, *Tests of alternative Quantum Theories with Neutrons*, Proceedings QCMC 2012, Vienna, Eds. H. Schmiedmayer and P. Walther, AIP Conf. Proc. 1633, 41-43 (2014).
3. St. Sponar, J. Klepp, R. Loidl, K. Durstberger-Renhofer, H. Geppert, G. Badurek, H. Rauch, and Y. Hasegawa, *Triple Entanglement in Neutron Interferometric and Polarimetric Experiments*, Journal of Physics: Conference Series, **340**, 012044 (2012); 5<sup>th</sup> European Conference on Neutron Scattering.
4. J. Klepp, St. Sponar, S. Filipp, M. Lettner, G. Badurek, and Y. Hasegawa, *Nonadditive mixed state phase in neutron optics*, In Foundations of probability and physics-5, Eds. L. Accardi, G. Adenier, C.A. Fuchs, G. Jaeger, A.Y. Khrennikov. J.A. Larsson and S. Stenholm, AIP Conf. Proc. 1101 (2009).
5. J. Klepp, St. Sponar, S. Filipp, M. Lettner, G. Badurek, and Y. Hasegawa, *Nonadditivity of Quantum Phases for mixed States*, Proceedings of the Junior Scientist Conference 2008, Vienna University of Technology, Wien, ISBN: 978-3-200-01612-5, 129 (2008).



### 3 Vorträge

#### Eingeladene Vorträge bei internationalen Konferenzen:

*Weak Values and Weak Measurements studied in Neutron Interferometry*, Joint Annual Meeting of Swiss Physical Society (SPS) and Austrian Physical Society (ÖPG), Zürich, Switzerland, Aug 26 - 30, 2019

*Measurement Uncertainty Relations & Which-Way Measurements studied in Neutron Interferometry*, Time and fundamentals of quantum mechanics Weizmann Institute of Science, Rehovot, Israel, Jan 28-31, 2019

*Weak Values, Path Reconstruction & Which-Way Measurements studied in Neutron Interferometry*, Particle Physics with Cold and Ultra-Cold Neutrons, Bad Honnef, Germany, Oct 24 - 26. 2018

*Operator-based, operational & entropic Measurement Uncertainty Relations studied in Neutron Optics*, 3<sup>rd</sup> International Conference on Quantum Foundations 2017 (ICQF15), Patna, India, Dec 4. - 09. 2017

*Weak Measurements & Quantum Paradoxes studied in Neutron Interferometry*, Workshop on Matter Wave Interferometry, Joint Quantum Institute University of Maryland and National Institute of Standards and Technology College Park, MD, USA, Sept 30. - Oct 2. 2016.

*Measurement-Disturbance Uncertainty Relations studied in Neutron Optics*, 1<sup>st</sup> International Conference on Quantum Foundations 2015 (ICQF15), Patna, India, Nov 30. - Dec 04. 2015

*Error-Disturbance Uncertainty Relation in Spin Measurements*, 4<sup>th</sup> Nagoya Winter Workshop on Quantum Information, Measurement, and Foundations, Nagoya University, Japan, Feb 18.-22. 2013

#### Beigetrogene Vorträge bei internationalen Konferenzen:

*Experimental Studies of Measurement Uncertainty Relations in Neutron Optics*, Quantum Frontiers & Fundamentals (QFF 2020), Bangalore, India, Jan 13. - 18. 2020

*Measurement Uncertainty Relations studied in Neutron Optics*, Quantum Africa 5 (QA 5), Stellenbosch, South Africa, Sept 2. - 6. 2019.

*Weak Measurements and Which-Way Measurements studied in Neutron Optics*, European Conference on Neutron Scattering (ECNS 2019), St. Petersburg, Russian Federation, June 30. - July 5. 2019.

***Weak Measurements & Weak Values studied in Neutron Interferometry***, Polarised Neutrons for Condensed-Matter Investigations (PNCMI 2018), Abingdon, UK, July 3. - 6. 2018.

***Experimental Demonstration of direct Path State Characterization by strongly measuring Weak Values in Neutron Interferometry***, AAV Anniversary Conference - Celebrating 30 Years of Weak Values (AAV 2018), Orange, USA, March 5. - 9. 2018.

***Experimental Demonstration of direct Path State Characterization by strongly measuring Weak Values in Neutron Interferometry***, The 10<sup>th</sup> International Conference on Neutron Scattering (ICNS 2017), Daejeon, Republic of Korea, July 9. - 13. 2017.

***Uncertainty Relations & Quantum Cheshire Cats studied in Neutron Optics***, The 6<sup>th</sup> European Conference on Neutron Scattering (ECNS 2015), Zaragoza, Spain, Aug 30.-Sept 04. 2015

***Error-Disturbance Uncertainty Relations and Quantum Cheshire Cats studied in Neutron Optics***, Quantum Theory: from foundations to technologies (QTFT), Växjö, Schweden, June 08.-11. 2015

***Error-disturbance uncertainty relations and the quantum Cheshire Cat studied in neutron optical experiments***, Frontiers in Matter Wave Optics (FOMO 2014), Chania, Crete, Oct 06.-10. 2014

***Uncertainty Relations and Quantum Cheshire Cats studied in Neutron Optics***, Quantum Africa 3 "Advances in Quantum Sciences" (QA 3), Rabat, Morocco, Sept 22.-26. 2014

***Neutron optical measurements studying quantum mechanics***, 3<sup>rd</sup> GRANIT Workshop "Quantum gravitational spectroscopy with ultracold systems", Les Houches, France, Mar 02.-07. 2014

***Foundations of Quantum Mechanics studied with Neutrons***, Quantum Africa 2 (QA2), Northern Drakensberg, South Africa, Sept 03.-07. 2012

***Multi-Entanglement in Neutron Interferometric Experiments***, 5<sup>th</sup> European Conference on Neutron Scattering (ECNS 2011), Prague, Czech Republic, July 17.-21. 2011

***Entanglement in Neutron Polarimetric Experiments***, Joint Annual Meeting of Swiss Physical Society (SPS) and Austrian Physical Society (ÖPG), Lausanne, Switzerland, June 15.-16. 2011

## 4 Projektmittel

Table 1: Forschungsprojekte

Projekttitle	Programm, Nr.	Laufzeit	Summe
Schwache Messungen und Unschärferelationen in der Neutronenoptik	FWF Einzelprojekt P 30677	2018/01/01 andauernd	339 k€
Schwache Messungen, Phasen und Verschränkung mit Neutronen	FWF Einzelprojekt P 24973	2013/01/01 - 2016/12/31	347 k€

zurück zu Lebenslauf Kapitel 1

## 5 Betreuung

Table 2: Mitbetreute akademische Arbeiten

Student	Titel der Arbeit	Typus	Jahr
Valentina Bauer	Installation and Adjustment of Neutron Interferometry Station at Atominstitut Wien <sup>†</sup>	Bachelor	2019
Armin Danner	Spin-Rotation Coupling in a Neutron Polarimeter Experiment*	Master	2019
Simon Hack	Investigating tight state-independent preparation uncertainty relation for Qubits utilizing neutrons <sup>†</sup>	Bachelor	2019
Bülent Demirel	Neutron optical experiments studying uncertainty relations of fundamental quantum measurements <sup>†</sup>	PhD	2018
Hermann Geppert	Experimental studies of a Bell-like inequality and a which-way measurement in neutron interferometry <sup>†</sup>	PhD	2017
Stefan Lindner	Delayed Choice in einem Quantum Cheshire Cat Experiment <sup>†</sup>	Master	2017
Tobias Denkmayr	Experimental investigation of weak values in massive quantum systems <sup>†</sup>	PhD	2016

<sup>†</sup> *Betreuer: Prof. Yuji Hasegawa*

\* *Betreuer: Prof. Gerald Badurek*

Laufende Mitbetreuung: Armin Danner (Diss), Niels Geerits (Diss), Elizabeth Kreuzgruber (Master) and Vito Pecile (Master)

## 6 Lehre

Table 3: Bisherige Lehrtätigkeit

Nummer	Titel	Typ	Jahr	Institut
130.005	Einführung in das Physikstudium <sup>†</sup>	VU	2019	E130
130.001	Grundlagen der Physik Ia <sup>†,◦</sup>	VU	2018/20	E130
130.002	Grundlagen der Physik Ib <sup>†</sup>	VU	2018/20	E130
130.003	Grundlagen der Physik IIa <sup>†</sup>	VU	2020	E130
130.001	Grundlagen der Physik I <sup>†</sup>	UE	2016	E130
138.008	Grundlagen der Physik II <sup>†</sup>	UE	2017	E130
134.125	Grundlagen der Physik III <sup>†</sup>	UE	2018	E130
1138.081	Physik Übungen II (für Chemiker)*	UE	2018	E141
141.064	Praktikum aus Neutronenphysik*	LU	2012 - laufend	E141
141.A12	Quantenphysik *	LU	2013 - laufend	E141
141.026	Projektarbeit Neutronenoptik *	PA	2016 - laufend	E141

<sup>†</sup> *Pflichtlehre*

\* *Wahlfächer*

◦ *Best Teaching Award 2019*

zurück zu Lebenslauf Kapitel [1](#)

## 7 Habilitationsfach:

### *Experimentelle Quantenmechanik*

Meine Forschung widmet sich grundlegenden Konzepten der Quantenmechanik, wie etwa *Verschränkung*, *Schwachen Messungen* oder *Unschärfe Relationen*. Hierbei kommen zwei bewährte neutronenoptische Verfahren, nämlich die *Silizium - Perfektkristall - Neutroneninterferometrie* und die *Neutronen Polarimetrie* (Interferenz von Spin Zustände) zum Einsatz.

## 8 Curriculum Vitae

### *Personal data*



Title: Dipl.-Ing. Dr. techn.  
Adresse: 1130 Vienna, Steinklammerg.19  
Place/Date of birth: Vienna, 18.06.1977  
Civilian Service: June 2005 - June 2006, Vienna  
Civil status: Married  
Nationality: Austria  
Email: sponar@tuwien.ac.at *and* stephan.sponar@gmx.net  
Web: [www.neutroninterferometry.com](http://www.neutroninterferometry.com)  
Work: TU Wien; Atominstitut, Stadionallee 2, 1020 Vienna  
ORCID: <https://orcid.org/0000-0002-6568-6045>

### **Education and university studies**

March 2011	PhD. (Dr. techn.) examination with distinction thesis: <i>Multi-Entanglement in Neutron Interferometric and Polarimetric Experiments</i> , Supervisor: Prof. Yuji Hasegawa
July 2006 - March 2011	PhD-Studies at the Atominstitut, TU-Wien (Vienna, Austria), employed by FWF
Jan 2005	Master's Degree (Dipl.-Ing.) in Technical Physics, TU-Wien (Vienna) thesis: <i>Non-cyclic geometric phases in neutron polarimetric experiments</i> (Supervisor: Prof. Gerald Badurek)
1995 - 2005	Physics studies at the TU-Wien (Vienna, Austria)
1987-1995	Realgymnasium, Rosasg., 1120 Vienna (Matura May 1995)

### **Language skills:**

English, German, French (basic level)

**Working Experiences**

Jan 2016 - now	Senior-Scientist Position, TU-Wien (Vienna, Austria) Atominstitut, Neutron and Quantum Physics Group
Nov 2011 - Jan 2016	Post-Doctoral Position, TU-Wien (Vienna, Austria) Atominstitut, Neutron and Quantum Physics Group
May 2006 - March 2011	Scientific stays at Institute Laue Langevin (ILL) in Grenoble, France

**Teaching**

Ue Grundlagen der Physik Ia, Ue Grundlagen der Physik Ib, Ue Grundlagen der Physik II, Ue Grundlagen der Physik III, Physik Proseminar II, Quantenphysik, Praktikum aus Neutronenphysik

(for detailed table see Section [13](#))

**Research Projects**

- *Weak Measurements, Phases and Entanglement in Neutron Optics*  
FWF P 24973: Jan. 2013 - Dec. 2016
- *Weak Measurements and Uncertainty Relations in Neutron Optics*  
FWF P 30677: Jan. 2018, running

(for details of the projects see Section [11](#))

## 9 Publication List

### Five most important publications:

- I. T. Denkmayr, H. Geppert, H. Lemmel, M. Waegell, J. Dressel, Y. Hasegawa, and St. Sponar, *Experimental demonstration of direct path state characterization by strongly measuring weak values in a matter-wave interferometer*, Physical Review Letters **118**, 010402 (2017) [quant-ph/1604.04102].
- II. G. Sulyok and St. Sponar, *Is Heisenberg's error-disturbance uncertainty relation violated?: Experimental study of competing approaches*, Physical Review A **96**, 022137 (2017)
- III. St. Sponar, T. Denkmayr, H. Geppert, H. Lemmel, A. Matzkin, J. Tollaksen, and Y. Hasegawa, *Weak values obtained in matter-wave interferometry*, Physical Review A **92**, 062121 (2015) [quant-ph/1404.2125].
- IV. T. Denkmayr, H. Geppert, St. Sponar, H. Lemmel, A. Matzkin, J. Tollaksen, and Y. Hasegawa, *Observation of a quantum Cheshire Cat in a matter-wave interferometer experiment*, Nature Communications **5**, 4492 (2014) **OPEN**.
- V. J. Erhart, St. Sponar, G. Sulyok, G. Badurek, M. Ozawa, and Y. Hasegawa, *Experimental demonstration of a universally valid error-disturbance uncertainty relation in spin-measurements*, Nature Physics **8**, 185-189 (2012) [quant-ph/1201.1833].

### Publications currently under review:

- i) St. Sponar, Armin Danner, Kazuma Obigane, Simon Hack, and Yuji Hasegawa, *Experimental test of tight state-independent preparation uncertainty relations for qubits*, submitted to *Phys. Rev. Lett.* (Feb 2020).

### Peer-reviewed publications:

39. A. Danner, B. Demirel, W. Kersten, R. Wagner, H. Lemmel, St. Sponar and Y. Hasegawa, *Spin-rotation coupling observed in neutron interferometry*, npj Quantum Information **6**, 23 (2020).
38. Bülent Demirel, St. Sponar, and Yuji Hasegawa, *Measurements of Entropic Uncertainty Relations in Neutron Optics*, Applied Science **10**, 1087 (2020).
37. R. Wagner, L. Brandl, W. Kersten, St. Sponar, Y. Hasegawa, C. Huber, F. Bruckner and D. Suess, *3D printed magnets for neutron spin manipulation*, EPJ Web Conf. **219**, 10008 (2019).

36. W. Kersten, L. Brandl, R. Wagner, C. Huber, F. Bruckner, Y. Hasegawa, D. Suess, and St. Sponar, *Additive-Manufactured and Topology-Optimized Permanent Magnet Spin Rotator for Neutron Interferometry*, Physical Review Applied **12**, 014023 (2019).
35. A. Danner, B. Demirel, St. Sponar, and Y. Hasegawa, *Development and performance of a miniaturised spin rotator suitable for neutron interferometer experiments*, Journal of Physics Communications **3**, 035001 (2019).
34. B. Demirel, St. Sponar, A. A. Abbott, C. Branciard, and Y. Hasegawa, *Experimental test of an entropic measurement uncertainty relation for arbitrary qubit observables*, New Journal of Physics **21**, 013038 (2019).
33. M. Blackener, B. Demirel, I. Drevensek-Olenik, M. Fally, P. Flauger, P. Geltenbort, Y. Hasegawa, R. Kurinjimala, M. Lioen, C. Pruner, St. Sponar, Y. Tomita, J. Klepp, *Monte-Carlo simulation of neutron transmission through nanocomposite materials for neutron-optics applications*, Nuclear Instruments and Methods in Physics Research A **916**, 154–157 (2019).
32. H. Geppert-Kleinrath, T. Denkmayr, St. Sponar, H. Lemmel, T. Jenke, and Y. Hasegawa, *Multifold paths of neutrons in the three-beam interferometer detected by a tiny energy kick*, Physical Review A **97**, 052111 (2018).
31. T. Denkmayr, J. Dressel, H. Geppert-Kleinrath, Y. Hasegawa, and St. Sponar, *Weak values from strong interactions in neutron interferometry*, Physica B **551**, 339-346 (2018).
30. M. Waegell, T. Denkmayr, H. Geppert, D. Ebner, T. Jenke, Y. Hasegawa, St. Sponar, J. Dressel, and J. Tollaksen, *Confined Contextuality in Neutron Interferometry: Observing the Quantum Pigeonhole Effect*, Physical Review A **96**, 052131 (2017) [quant-ph/1609.06046].
29. G. Sulyok and St. Sponar, *Is Heisenberg's error-disturbance uncertainty relation violated?: Experimental study of competing approaches*, Physical Review A **96**, 022137 (2017).
28. T. Denkmayr, H. Geppert, H. Lemmel, M. Waegell, J. Dressel, Y. Hasegawa, and St. Sponar, *Experimental demonstration of direct path state characterization by strongly measuring weak values in a matter-wave interferometer*, Physical Review Letters **118**, 010402 (2017) [quant-ph/1604.04102].
27. B. Demirel, St. Sponar, G. Sulyok, M. Ozawa, and Y. Hasegawa, *Residual error-disturbance uncertainties in successive spin- $1/2$  measurements tested in matter-wave optics*, Physical Review Letters **117**, 140402 (2016) [quant-ph/1511.03462].
26. St. Sponar, *Error-disturbance uncertainty relations in neutron spin measurements*, International Journal of Quantum Information **14**, 1640016 (2016).



25. St. Sponar, T. Denkmayr, H. Geppert, and Y. Hasegawa, *Fundamental Features of Quantum Dynamics Studied in Matter-Wave Interferometry—Spin Weak Values and the Quantum Cheshire-Cat*, *Atoms* **4**, 11 (2016). **OPEN**
24. St. Sponar, T. Denkmayr, H. Geppert, H. Lemmel, A. Matzkin, J. Tollaksen, and Y. Hasegawa, *Weak values obtained in matter-wave interferometry*, *Physical Review A* **92**, 062121 (2015) [quant-ph/1404.2125].
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22. B. Demirel, St. Sponar, and Y. Hasegawa, *Measurement of the spin-rotation coupling in neutron polarimetry*, *New Journal of Physics* **17**, 023065 (2015).
21. St. Sponar, G. Sulyok, J. Erhart, and Y. Hasegawa, *Error-Disturbance Uncertainty Relations in Neutron-Spin Measurements*, *Advances in High Energy Physics* **2014**, 735398 (2014).
20. T. Denkmayr, H. Geppert, St. Sponar, H. Lemmel, A. Matzkin, J. Tollaksen, and Y. Hasegawa, *Observation of a quantum Cheshire Cat in a matter-wave interferometer experiment*, *Nature Communications* **5**, 4492 (2014) **OPEN**.
19. J. Klepp, St. Sponar, and Y. Hasegawa, *Fundamental phenomena of quantum mechanics explored with neutron interferometers*, *Progress of Theoretical and Experimental Physics* **2014**, 082A0 (2014) [quant-ph/1407.2526].
18. H. Geppert, T. Denkmayr, St. Sponar, H. Lemmel, and Y. Hasegawa, *Improvement of the polarized neutron interferometer setup demonstrating violation of a Bell-like inequality*, *Nuclear Instruments and Methods in Physics Research A* **763**, 417–423 (2014) [quant-ph/1404.3512].
17. G. Sulyok, St. Sponar, J. Erhart, G.Badurek, M. Ozawa, and Y. Hasegawa, *Violation of Heisenberg’s error-disturbance uncertainty relation in spin measurements*, *Physical Review A* **88**, 022110 (2013) [quant-ph/1305.7251].
16. St. Sponar, J. Klepp, K. Durstberger-Rennhofer, H. Geppert, M. Both, C. S. Schmitzer, H. Bartosik, G. Badurek, and Y. Hasegawa, *High-efficiency manipulations of triply entangled states in neutron polarimetry*, *New Journal of Physics* **14**, 053032 (2012).
15. J. Erhart, St. Sponar, G.Sulyok, G.Badurek, M. Ozawa, and Y. Hasegawa, *Experimental demonstration of a universally valid error-disturbance uncertainty relation in spin-measurements*, *Nature Physics* **8**, 185-189 (2012) [quant-ph/1201.1833].
14. Y. Hasegawa, C. Schmitzer, H. Bartosik, J. Klepp, St. Sponar, K. Durstberger-Rennhofer, and G. Badurek, *Falsification of Leggett’s model using neutron matter-waves*, *New Journal of Physics* **14**, 023039 (2012).

13. St. Sponar, J. Klepp, R. Loidl, S. Filipp, K. Durstberger, R. Bertlmann, G. Badurek, H. Rauch, and Y. Hasegawa, *Geometric phase in entangled systems: A single-neutron interferometer experiment*, Physical Review A **81**, 042113 (2010) [quant-ph/0907.4909].
12. St. Sponar, J. Klepp, K. Durstberger, R. Loidl, S. Filipp, M. Lettner, R. Bertlmann, G. Badurek, H. Rauch, and Y. Hasegawa, *New aspects of geometric phases in experiments with polarized neutrons*, Journal of Physics A: Mathematical and Theoretical **43**, 354015 (2010).
11. St. Sponar, J. Klepp, C. Zeiner, G. Badurek, and Y. Hasegawa, *Violation of a Bell-like inequality for spin-energy entanglement in neutron polarimetry*, Physics Letters A **374**, 431-434 (2010) [quant-ph/0907.4654].
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8. H. Bartosik, J. Klepp, C. Schmitzer, St. Sponar, A. Cabello, H. Rauch, and Y. Hasegawa, *Experimental test of quantum contextuality in neutron interferometry*, Physical Review Letters **103**, 040403 (2009) [quant-ph/0904.4576].
7. Y. Hasegawa, G. Badurek, S. Filipp, J. Klepp, R. Loidl, St. Sponar, and H. Rauch, *Entanglement between degrees of freedom of single-neutrons*, Nuclear Instruments and Methods in Physics Research A **611**, 310-313 (2009).
6. St. Sponar J. Klepp, R. Loidl, S. Filipp, G. Badurek, Y. Hasegawa, and H. Rauch, *Coherent energy manipulation in single-neutron interferometry*, Physical Review A **78**, 061604(R) (2008) [quant-ph/0803.3545].
5. St. Sponar, J. Klepp, G. Badurek, and Y. Hasegawa, *Zero-field and Larmor spinor precessions in a neutron polarimeter experiment*, Physics Letters A **372**, 3153-3156 (2008) [quant-ph/0802.1411].
4. J. Klepp, St. Sponar, S. Filipp, M. Lettner, G. Badurek, and Y. Hasegawa, *Observation of Nonadditive Mixed-State Phases with Polarized Neutrons*, Physical Review Letters **101**, 150404 (2008) [quant-ph/0809.0572].
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1. M. Zehetmayer, M. Eisterer, St. Sponar, H. W. Weber, A. Wisniewski, R. Puzniak, P. Panta, J. Karpinski, *Magnetic properties of superconducting  $HgBa_2CuO_{4+d}$  single crystals in the overdoped state before and after particle irradiation*, Physica C **418**, 73 - 86 (2005).

#### Conference proceedings:

1. St. Sponar, H. Geppert, T. Denkmayr, H. Lemmel and Y. Hasegawa, *Asking Neutrons where they have been*, J. Phys.: Conf. Ser. 1316 012002 (2019).
2. St. Sponar, J. Klepp, C. Schmitzer, H. Bartosik, K. Durstberger-Renhofer, G. Badurek, and Y. Hasegawa, *Tests of alternative Quantum Theories with Neutrons*, Proceedings QCMC 2012, Vienna, Eds. H. Schmiedmayer and P. Walther, AIP Conf. Proc. 1633, 41-43 (2014).
3. St. Sponar, J. Klepp, R. Loidl, K. Durstberger-Renhofer, H. Geppert, G. Badurek, H. Rauch, and Y. Hasegawa, *Triple Entanglement in Neutron Interferometric and Polarimetric Experiments*, Journal of Physics: Conference Series, **340**, 012044 (2012); 5<sup>th</sup> European Conference on Neutron Scattering.
4. J. Klepp, St. Sponar, S. Filipp, M. Lettner, G. Badurek, and Y. Hasegawa, *Nonadditive mixed state phase in neutron optics*, In Foundations of probability and physics-5, Eds. L. Accardi, G. Adenier, C.A. Fuchs, G. Jaeger, A.Y. Khrennikov. J.A. Larsson and S. Stenholm, AIP Conf. Proc. 1101 (2009).
5. J. Klepp, St. Sponar, S. Filipp, M. Lettner, G. Badurek, and Y. Hasegawa, *Nonadditivity of Quantum Phases for mixed States*, Proceedings of the Junior Scientist Conference 2008, Vienna University of Technology, Wien, ISBN: 978-3-200-01612-5, 129 (2008).

## 10 Talks

### Invited conference talks at international conferences:

*Weak Values and Weak Measurements studied in Neutron Interferometry*, Joint Annual Meeting of Swiss Physical Society (SPS) and Austrian Physical Society (ÖPG), Zürich, Switzerland, Aug 26 - 30, 2019

*Measurement Uncertainty Relations & Which-Way Measurements studied in Neutron Interferometry*, Time and fundamentals of quantum mechanics Weizmann Institute of Science, Rehovot, Israel, Jan 28-31, 2019

*Weak Values, Path Reconstruction & Which-Way Measurements studied in Neutron Interferometry*, Particle Physics with Cold and Ultra-Cold Neutrons, Bad Honnef, Germany, Oct 24 - 26. 2018

*Operator-based, operational & entropic Measurement Uncertainty Relations studied in Neutron Optics*, 3<sup>rd</sup> International Conference on Quantum Foundations 2017 (ICQF15), Patna, India, Dec 4. - 09. 2017

*Weak Measurements & Quantum Paradoxes studied in Neutron Interferometry*, Workshop on Matter Wave Interferometry, Joint Quantum Institute University of Maryland and National Institute of Standards and Technology College Park, MD, USA, Sept 30. - Oct 2. 2016.

*Measurement-Disturbance Uncertainty Relations studied in Neutron Optics*, 1<sup>st</sup> International Conference on Quantum Foundations 2015 (ICQF15), Patna, India, Nov 30. - Dec 04. 2015

*Error-Disturbance Uncertainty Relation in Spin Measurements*, 4<sup>th</sup> Nagoya Winter Workshop on Quantum Information, Measurement, and Foundations, Nagoya University, Japan, Feb 18.-22. 2013

### Contributed conference talks at international conferences:

*Experimental Studies of Measurement Uncertainty Relations in Neutron Optics*, Quantum Frontiers & Fundamentals (QFF 2020), Bangalore, India, Jan 13. - 18. 2020

*Measurement Uncertainty Relations studied in Neutron Optics*, Quantum Africa 5 (QA 5), Stellenbosch, South Africa, Sept 2. - 6. 2019.

*Weak Measurements and Which-Way Measurements studied in Neutron Optics*, European Conference on Neutron Scattering (ECNS 2019), St. Petersburg, Russian Federation, June 30. - July 5. 2019.

***Weak Measurements & Weak Values studied in Neutron Interferometry***, Polarised Neutrons for Condensed-Matter Investigations (PNCMI 2018), Abingdon, UK, July 3. - 6. 2018.

***Experimental Demonstration of direct Path State Characterization by strongly measuring Weak Values in Neutron Interferometry***, AAV Anniversary Conference - Celebrating 30 Years of Weak Values (AAV 2018), Orange, USA, March 5. - 9. 2018.

***Experimental Demonstration of direct Path State Characterization by strongly measuring Weak Values in Neutron Interferometry***, The 10<sup>th</sup> International Conference on Neutron Scattering (ICNS 2017), Daejeon, Republic of Korea, July 9. - 13. 2017.

***Uncertainty Relations & Quantum Cheshire Cats studied in Neutron Optics***, The 6<sup>th</sup> European Conference on Neutron Scattering (ECNS 2015), Zaragoza, Spain, Aug 30.-Sept 04. 2015

***Error-Disturbance Uncertainty Relations and Quantum Cheshire Cats studied in Neutron Optics***, Quantum Theory: from foundations to technologies (QTFT), Växjö, Schweden, June 08.-11. 2015

***Error-disturbance uncertainty relations and the quantum Cheshire Cat studied in neutron optical experiments***, Frontiers in Matter Wave Optics (FOMO 2014), Chania, Crete, Oct 06.-10. 2014

***Uncertainty Relations and Quantum Cheshire Cats studied in Neutron Optics***, Quantum Africa 3 "Advances in Quantum Sciences" (QA 3), Rabat, Morocco, Sept 22.-26. 2014

***Neutron optical measurements studying quantum mechanics***, 3<sup>rd</sup> GRANIT Workshop "Quantum gravitational spectroscopy with ultracold systems", Les Houches, France, Mar 02.-07. 2014

***Foundations of Quantum Mechanics studied with Neutrons***, Quantum Africa 2 (QA2), Northern Drakensberg, South Africa, Sept 03.-07. 2012

***Multi-Entanglement in Neutron Interferometric Experiments***, 5<sup>th</sup> European Conference on Neutron Scattering (ECNS 2011), Prague, Czech Republic, July 17.-21. 2011

***Entanglement in Neutron Polarimetric Experiments***, Joint Annual Meeting of Swiss Physical Society (SPS) and Austrian Physical Society (ÖPG), Lausanne, Switzerland, June 15.-16. 2011

## 11 Projects

Table 4: Projects Activities

Project Titel	Type, ID	Running Time	Volume
Weak Measurements and Uncertainty Relations in Neutron Optics	FWF Stand Alone P 30677	2018/01/01 running	339 k€
Weak Measurements, Phases and Entanglement in Neutron Optics	FWF Stand Alone P 24973	2013/01/01 - 2016/12/31	347 k€

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## 12 Supervision

Table 5: Co-supervising Activities

Candidate	Thesis Titel	Type	Year
Valentina Bauer	Installation and Adjustment of Neutron Interferometry Station at Atominstytut Wien <sup>†</sup>	Bachelor	2019
Armin Danner	Spin-Rotation Coupling in a Neutron Polarimeter Experiment*	Master	2019
Simon Hack	Investigating tight state-independent preparation uncertainty relation for Qubits utilizing neutrons <sup>†</sup>	Bachelor	2019
Bülent Demirel	Neutron optical experiments studying uncertainty relations of fundamental quantum measurements <sup>†</sup>	PhD	2018
Hermann Geppert	Experimental studies of a Bell-like inequality and a which-way measurement in neutron interferometry <sup>†</sup>	PhD	2017
Stefan Lindner	Delayed Choice in einem Quantum Cheshire Cat Experiment <sup>†</sup>	Master	2017
Tobias Denkmayr	Experimental investigation of weak values in massive quantum systems <sup>†</sup>	PhD	2016

<sup>†</sup> *Supervisor: Yuji Hasegawa*

\* *Supervisor: Gerald Badurek*

Ongoing co-supervision: Armin Danner (PhD), Niels Geerits (PhD), Elizabeth Kreuzgruber (Master) and Vito Pecile (Master)

## 13 Teaching

Table 6: Teaching Activities

Course ID	Course Titel	Type	Year	Institut
130.005	Einführung in das Physikstudium <sup>†</sup>	VU	2019	E130
130.001	Grundlagen der Physik Ia <sup>†, ◦</sup>	VU	2018/20	E130
130.002	Grundlagen der Physik Ib <sup>†</sup>	VU	2018/20	E130
130.003	Grundlagen der Physik IIa <sup>†</sup>	VU	2020	E130
130.001	Grundlagen der Physik I <sup>†</sup>	UE	2016	E130
138.008	Grundlagen der Physik II <sup>†</sup>	UE	2017	E130
134.125	Grundlagen der Physik III <sup>†</sup>	UE	2018	E130
1138.081	Physik Übungen II (Chemistry)*	UE	2018	E141
141.064	Praktikum aus Neutronenphysik*	LU	2012 - now	E141
141.A12	Quantenphysik *	LU	2013 - now	E141
141.026	Projektarbeit Neutronenoptik *	PA	2016 - now	E141

<sup>†</sup> *compulsory lecture course*

\* *optional lecture course*

◦ *Best Teaching Award 2019*

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## 14 Habilitation Subject:

### *Experimental Quantum Mechanics*

My research is dedicated to fundamental concepts of quantum mechanics, covering topics such as *entanglement*, *weak measurements* and *uncertainty relations*. Two well established neutron optical techniques, namely *neutron interferometry* (more precisely silicon perfect crystal interferometry) and *neutron polarimetry*, also referred to as "spin-interferometry", provide an appropriate research approach.