Cheryl Patrick (cpatrick@ed.ac.uk)

Contact Information

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Affiliation

University of Edinburgh, UK: STFC Ernest Rutherford Fellow (2021-6 + proleptic appointment)
University College London, UK: Research associate (2016-2021)

Education

Northwestern University, Evanston, IL, USA
2010-2016: PhD in physics, supervised by Prof. Heidi Schellman
Thesis: Double-differential charged-current quasi-elastic antineutrino scattering cross section at MINERvA (Springer thesis prize 2017)
2012: Master of Science, Physics
Magdalen College, University of Oxford, UK
1997: BA, Physics (first class)
2001: MA

Experience in Industry

Over 10 years' professional software development experience, including C++ and Java programming, database design, project management, team leadership, customer liaison, and business analysis.
2008-2010: **Web developer, Cabana A/S, Denmark**
2003-2008: **Software engineering contractor, PIPS Technology Ltd, UK**
2000-2003: **Team leader / senior design engineer, Telsis Ltd, UK**
1997-2000: **IT Consultant, Hampshire County Council IT Services, UK**

Prizes and Awards

2021: **STFC Ernest Rutherford Fellowship**: Unlocking the mysteries of the neutrino and its mass through the nucleus
2017: **Springer thesis prize**
2014: School competition winner: NuSTEC Neutrino Generator School
2012: Northwestern Integrated Science Programme: award for service through teaching

Research experience

My research is in neutrino physics, with a particular interest in how the nucleus affects our ability to understand neutrino processes. On **SuperNEMO (2016-now): double-beta decay**, I coordinate all the experiment's **analyses**, including machine-learning projects to overhaul track reconstruction and to measure sensitivity, novel techniques to constrain the quenched β-decay constant g_A, and simulation analyses that have affected detector design decisions. I developed SuperNEMO's **standard analysis and validation software**, streamlined code management and documentation procedures, manage tracker commissioning, and coordinate the UK effort towards the data commissioning analysis. I have led installation and commissioning trips to the detector in France.

On **DUNE (2019-now): neutrino oscillations**, I was in charge of the near detector conceptual design report's interactions chapter. To expand and educate the Neutrino Interactions and Standard Model group, which I co-convene, I organised the 173-participant **DUNE Neutrino-Interactions Summer School 2021**, where I taught interaction theory, and designed and led all the interactive activities. I am now starting to coordinate the interactions analysis effort. I contributed to a white paper proposing a plan to streamline modelling in generators. On **MINERvA, 2010-16): neutrino scattering**, I measured the world's first antineutrino double-differential quasi-elastic scattering cross section in the few-GeV range, created training material on cross sections and uncertainty, and led daily data processing and metadata management. I led an analysis of eGENIE pion-production simulation with the **e4nu: electrons for neutrinos** collaboration, to compare with CLAS electron-scattering data.

Research Leadership

I am the **analysis co-ordinator** of the 100-person SuperNEMO experiment. As well as leading simulation analysis and giving strategic guidance and scrutiny on SuperNEMO, I coordinate data analysis on NEMO-3's half-million $\beta\beta$ decay events. As SuperNEMO's **deputy physics coordinator**, I have significant involvement in planning and decision making on simulation production, data management, reconstruction and software. I am an active member of the SuperNEMO **Steering Committee**, and serve on the **Technical Board**, **Institutional Board** and **Speakers' Bureau**. I am taking a lead role in tracker commissioning and preparation for physics data, both onsite and remotely.

I am a **Neutrino Interactions and Standard Model convener on DUNE**, and serve on the DUNE Near-Detector Physics Board.

Academic Leadership

I have served as a **peer reviewer** for Eur.Phys.J C (double-beta decay) and PTEP (cross sections). I am an elected member and the newsletter committee chair of the **IOP Astroparticle Physics committee**, and organised UCL's high-energy physics seminar programme.

The University of Edinburgh's School of Physics and Astronomy has nominated me to take part in the 2021-22 Research Leader Programme.

Presentations and posters

My **11 conference presentations** include the **invited double-beta decay plenary at the Institute of Physics Joint APP and HEPP Annual Conference 2019**, as well as plenary talks at the internationally renowned **Rencontres de Moriond 2015** (Italy) and **DBD 18 (International workshop on double-beta decay and underground science)** (Hawai'i). I was invited to represent the UK neutrino community at the 'Challenges in theory of heavy nuclei' nuclear symposium, and to give a summary talk at the Fermilab Generator Tools workshop. I have presented **five posters**, and given **13 seminars, five internationally**, on neutrino cross sections and double-beta decay. These include both the **Fermilab Wine and Cheese** and Fermilab Neutrino Seminar.

Mentoring

I was **academic co-supervisor** to UCL PhD student M Ceschia, and proposed his project to redesign SuperNEMO reconstruction using convolutional neural networks. I supervised M Kynaston (**MSci**) and N Gadhia (**MSc**) on e4nu projects. I assisted with PhD supervision of four other UCL students, mentored summer student A Klustova, and supervised a collaboration between UCL and the Joint Biosecurity Committee (3 PhD students). I chaired UCL's $\beta\beta$ group meetings. As SuperNEMO analysis coordinator, I support the SuperNEMO-UK students, international students and postdocs, with data analysis. At Edinburgh, I am second supervisor for PhD student H Parkinson, will supervise senior honours student E Li, will be a chair at the PhD poster evening, and have proposed two Master's projects. I have been promised a PhD student next year.

Teaching

My experience includes lecturing for a first-year mechanics course; demonstrating and marking mechanics, modern physics, Python and machine-learning labs; holding office hours; and supervising a group for Python mini-projects. I won **Northwestern's Integrated Science programme's award for service through teaching**, and was chosen and trained to design and lead two workshops as part of Northwestern's new teaching-assistant conference. **In 2019, I was invited to lecture on double-beta decay and direct mass measurements at the International Neutrino Summer School in the USA**. At Edinburgh, I will be a physics 1b lab leader next term.

Public engagement

I write and perform science songs and videos in public and on YouTube, including the *Standard Model Song* in Robin Ince's *Nine Lessons and Carols for Curious People* and *SuperNEMO: the Musical* for Pint of Science. I have been involved in youth outreach including UCL's Your Universe, ATLAS Masterclasses, IOP's Big Bounce (as part of Edinburgh's Remote^3 team), and the Chicago Museum of Science and Industry's Hot Careers. I also volunteered teaching programming through Code First: Girls, and at Chicago's Artifice after-school program for disadvantaged children.

Selected publications

My full publication list with the SuperNEMO, NEMO-3, DUNE and MINERvA collaborations can been seen by searching for my ORCID iD: https://orcid.org/0000-0002-0713-7515

R. Arnold et al (SuperNEMO collaboration), **Measurement of the distribution of ^{207}Bi depositions on calibration sources for SuperNEMO** *JINST 16 (2021) T07012 (2021)*
This paper presents a novel technique for characterising the ^{207}Bi sources used for energy calibration of the SuperNEMO detector, which was used to select the most appropriate sources. As committee chair for this paper, I revised text, produced figures, collated comments from internal and external reviewers, and managed the entire process of getting the paper from draft through to publication.

DUNE Collaboration, **Deep Underground Neutrino Experiment (DUNE) Near Detector Conceptual Design Report** *Instruments. 5(4):31 (2021)*
The CDR describes DUNE's proposed near detector suite. I edited the cross sections chapter of the CDR, and wrote a substantial part of the content, explaining the importance of cross section measurements, the types of interactions applicable to the DUNE energy range, and the significance and challenge of nuclear effects. I also selected various case studies to demonstrate the detector's response to key interaction signatures, showing its excellent ability to reconstruct final-state pion multiplicity, which is very sensitive to interaction model; and studying nuclear effects by looking at final-state kinematic imbalance perpendicular to the neutrino beam.

R. Arnold et al (NEMO-3 collaboration), **Final results on ^{82}Se double beta decay to the ground state of ^{82}Kr from the NEMO-3 experiment**, *Eur. Phys. J. C (2018) 78: 821 (2018)*
This UCL-led analysis used NEMO-3's 82Se dataset to calculate a half-life for the Standard Model $2\nu\beta\beta$ decay. The unique NEMO technology distinguishes individual electron energies, allowing a fit to two decay models – the higher-state dominance (HSD) model, where decays take place via many different excited states of the intermediate ^{82}Br nucleus; and the single-state dominance (SSD) model, which decays via a single intermediate state. The data preferred SSD with 2σ significance; a similar analysis on our half-million ^{100}Mo dataset (Eur. Phys. J. C (2019) 79: 440) showed a clear preference for SSD. I am currently looking at extending the NEMO-3 data analyses to look beyond the simple SSD/HSD dichotomy, to attempt to constrain the nuclear matrix element and quenching of the axial coupling constant g_A. An improved version of this analysis on SuperNEMO data, which I plan to supervise, should yield 5σ sensitivity to SSD vs HSD.

C.E. Patrick et al (MINERvA collaboration), **Measurement of the muon anti-neutrino double-differential cross section for quasi-elastic scattering on hydrocarbon at $E_\nu \approx 3.5$ GeV**, *Phys. Rev. D 97, 052002 (2018)*
My calculation of the anti-neutrino scattering cross section at MINERvA improved on the initial single-differential measurement with an improved reconstruction and analysis procedure, updated systematic uncertainties, and improved nuclear interaction models. The double-differential kinematics give clearer distinctions between nuclear models, allowing us to determine that the fit to data can be greatly improved by using a model that incorporates nuclear effects such as weak nuclear screening and two-particle, two-hole enhancements.

Cheryl E. Patrick, **Measurement of the Antineutrino Double-Differential Charged-Current Quasi-Elastic Scattering Cross Section at MINERvA**, *ISBN 978-3-319-69086-5* My thesis analysis, the world's first calculation of a double-differential antineutrino-nucleus scattering cross section at the DUNE energy range, was published as a book following the award of the 2017 Springer Thesis Prize. The analysis studied a key signal process for oscillation experiments, which is strongly affected by poorly-understood nuclear effects. My measurement included over forty sources of systematic uncertainty, and comparisons to various nuclear models using the GENIE and NuWro neutrino event generators.

T. Walton et al (MINERvA collaboration), **Measurement of muon plus proton final states in ν_μ Interactions on Hydrocarbon at $\langle E_\nu \rangle = 4.2$ GeV**, *Phys. Rev. D 91, 071301 (2015)* I

served on the paper review committee for this analysis, which studied the kinematics of the muon and proton produced in quasi-elastic neutrino-nucleus scattering. By including the hadronic information in the analysis, we could study final-state interactions. This was particularly evident in the angle between the muon and proton tracks, where FSI makes a significant difference to the distribution. The analysis showed the importance of considering FSI, and that its strength was underestimated by the GENIE simulation.

L. Fields et al (MINERvA collaboration), **Measurement of Muon Antineutrino Quasi-Elastic Scattering on a Hydrocarbon Target at $E_\nu \approx 3.5$ GeV**, *Phys. Rev. Lett. 111, 022501 (2013)* MINERvA's first ever analyses were a pair of single-differential cross section measurement for neutrino and antineutrino scattering on scintillator. I assisted in the antineutrino analysis, calculating the magnitude of various systematic uncertainties. I later updated the analysis to produce a combined neutrino-antineutrino correlation matrix, using the results of Phys. Rev. Lett. 111, 022502 (2013); to include improved neutrino flux modelling; and to compare to additional nuclear models. I presented these results at conferences.