UNIVERSITY OF LIVERPOOL

Department of Mathematical Sciences

MATHEMATICAL SCIENCES

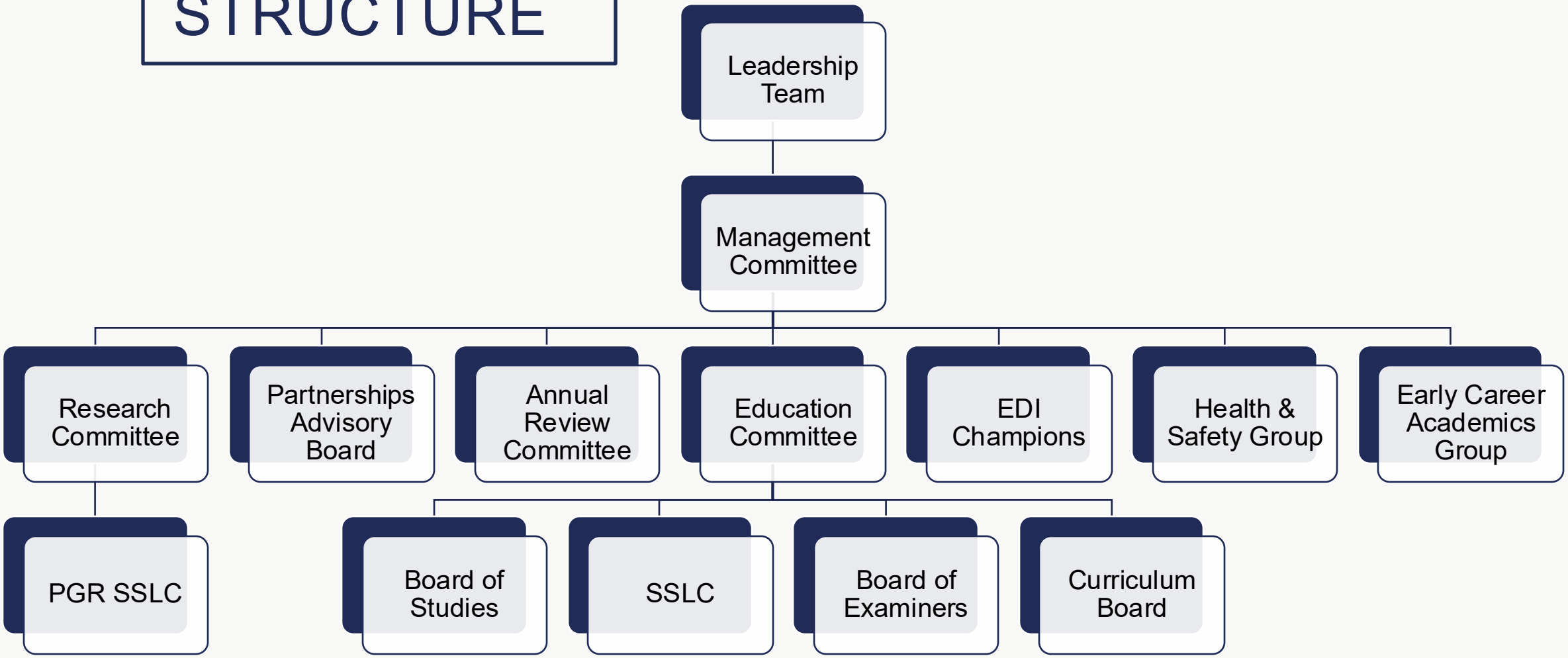
PDRA AWAY DAY OCTOBER 2025

Professor Daniel Colquitt
Head of Department
Department of Mathematical Sciences

MATHEMATICAL SCIENCES

ABOUT US

COMMITTEE STRUCTURE



KEY CONTACTS

Dan Colquitt

HoD

Thomas Teubner

Deputy HoD
Research

Anna Pratoussevitch

Deputy HoD
Education

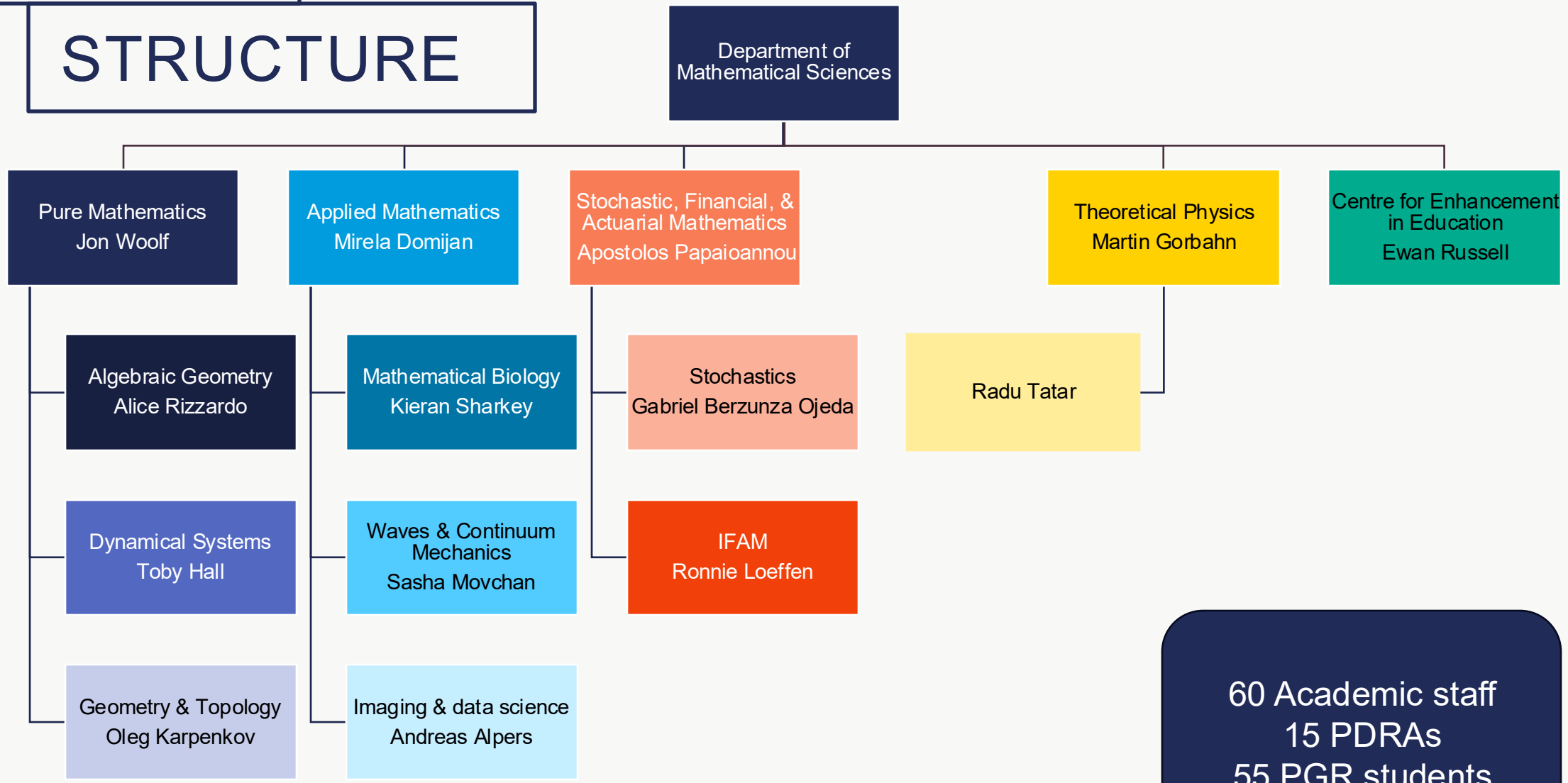
Kieran Sharkey

Chair
DMSRC

ECA

Lead

SECTION STRUCTURE



60 Academic staff
15 PDRAs
55 PGR students

APPLIED MATHEMATICS

“Our research is highly interdisciplinary and often finds application in a wide variety of fields from medical and healthcare, to the energy and oil industry, civil engineering, and geophysics. We have strong collaborative links with industry, other academic institutions, and NHS Trusts.”

Mathematical Biology

- Variational modelling, nonlinear optimization (theory & algos); image restoration, segmentation & co-registration
- Population dynamics, epidemiology, evolution, systems biology & multi-scale modelling, biological fluid dynamics

Waves & Continuum Mechanics

- Partial differential equations, wave propagation and scattering, cloaking, metamaterials, material science

Currently funded research projects

MUSICA (Industry funding)
BATNav (EPSRC)
Multiphysical multiscale modelling (Leverhulme)
Training & Professional Development (Consultancy)
Optimal grain designs (EPSRC)
OxLiv Impact Assessment Modelling (CEPI)
Emmy Noether Fellowship (LMS)
Analytical tools for FFX studies (MRC)
Fluid induce Seismicity (RS)

PURE MATHEMATICS

“The unifying thread running through all three research groups is the power of multi-dimensional geometrical thinking in revealing and comprehending the structure of diverse phenomena in mathematics and its applications.”

Three research groups

- Algebraic geometry
- Dynamical systems
- Geometry & Topology

Covering four areas of research

- Algebraic geometry
- Complex and topological dynamics
- Number and ergodic theory
- Hyperbolic geometry and singularity theory

Notable highlights & projects

Highly international fundamental research

Distinguished academics (FRS, Learned society medals)

Recent resolution of longstanding Eremenko's Conjecture

Curve counting theory (EPSRC)

Leverhulme visiting Professorships

S F + A

MATHEMATICS

Stochastics + IFAM

- Probability theory, Applied probability, Mortality modelling
- Financial Inclusion, Social Finance, Actuarial mathematics
- Statistics, Stochastic analysis, uncertainty quantification

“Our goal is to understand, describe and analyse random phenomena and structures. More generally, we are interested in the mathematics of randomness.

We contribute to society by finding solutions to financial problems and influencing governments and policymakers. Become an international hub for actuarial and financial maths collaborations.”

Currently funded research projects

Microfinance & Insurance (AIMS)

Emerging insurance markets (ILO & UN)

Extreme events – “Black Swans” (Pandemic Institute)

Mortality tables in emerging economies (BEAC)

THEORETICAL PHYSICS

Strings + Particles

- Quantum Field Theory, Perturbative loop computations
- Precision Phenomenology, Lattice QFT, application of AI
- Dark Matter & Dark Energy, String theory compactifications,
- Supersymmetric theories, Black Hole physics & Cosmology

Particles: *"Theoretical studies of the elementary particles and forces, developing testable theories which lie beyond the Standard Model of particle physics."*

Strings: *"We provide String Theory-inspired models related to fundamental questions in particle physics and cosmology"*

Notable highlights

- STFC CG
- Two UKRI FLFs
- Direct collaborations with PP group and part of muon precision physics programme, funding from Leverhulme Int. Prof. Graziano Venanzoni)
- Particle Physics Frontier
- Leadership in DiRAC (High Performance Computing Facility), conf. Lattice2024 @ UoL
- Excellent success in securing external fellowships

RESEARCH PRIORITIES

Increase research income

- Take advantage of momentum behind Data Science & AI – maths underpins everything!
- Focus on leading or contributing to large multi-disciplinary research projects
- Capitalise on Fellowship successes
- Horizon-scan for non-traditional funding routes
- Collaborate with industry, government, etc.

Increase overall output quality

- Revised output evaluation programme
- Focus on what really matters

Develop, document, & showcase impact

- Renewed focus on impact
- Everyone can contribute to impact
- Maths has a very long pipeline
- If unsure, document it
- Tell someone about it!

Sustainability of research groups

- Succession planning
- Fellowships – are you applying?
- Income

SUPPORT & OPPORTUNITIES

Get involved in departmental life!

- Research group meetings
- Seminars
- Colloquia
- Outreach
- ECA group

Funding applications

- Mentorship
- Technical & lay review
- Think about fellowships
- Speak with your section / group lead / PI

Broaden your horizons

- Maths underpins everything
- Unlikely that you will remain in precisely the same area for life
- Investigate links with research institutes, private sector, public sector, etc.
- Talk to people outside your field
- Say yes more

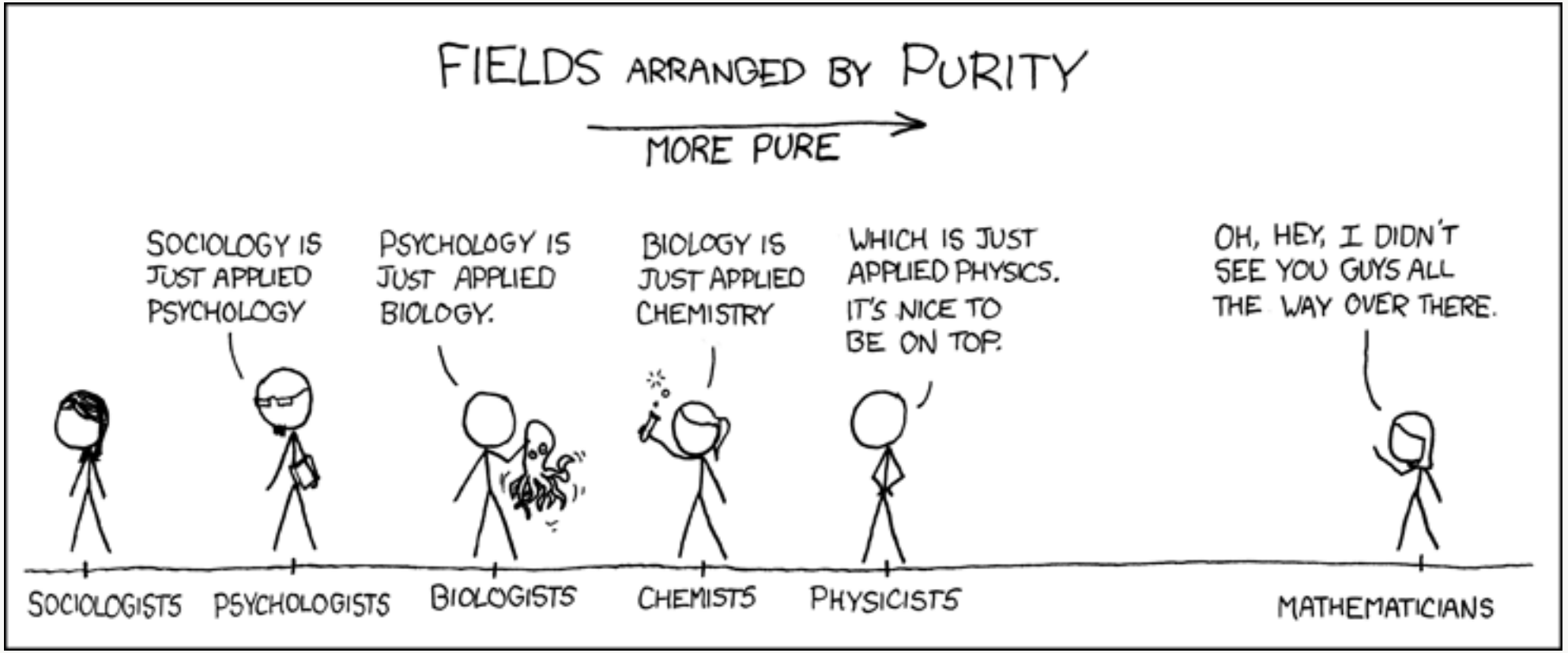
Training available

- The Academy
- Summer Schools
- Conferences, workshops, visits

PDRA RESEARCH HIGHLIGHTS

MATHS IS

EVERYWHERE

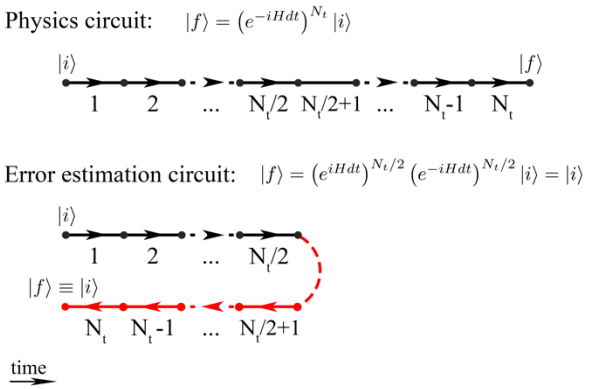


Emanuele Mendicelli (he/him)

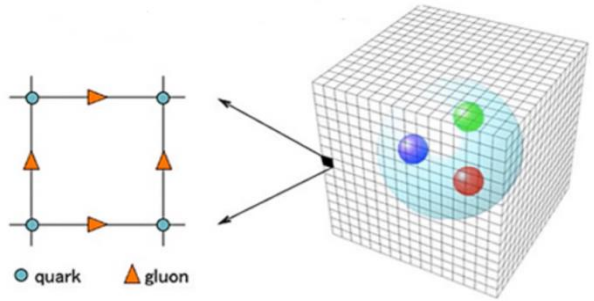
Research Interests:

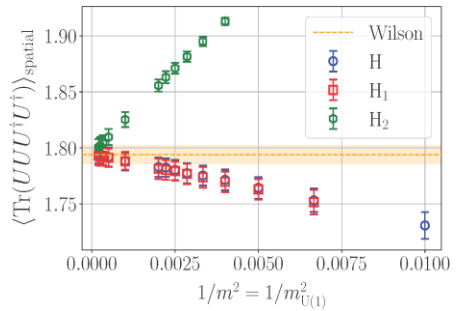
Quantum Computing for Lattice Gauge Theories

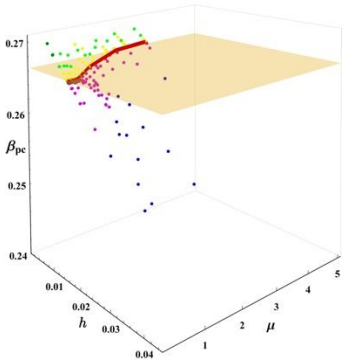
- **Quantum computing**
  - Particle Simulations on Quantum Computers
  - Time Evolution
  - Error Mitigation
  - Quantum Variational Methods



- **Lattice gauge theories**
  - Lattice Simulations for Particle Physics
  - Phase Diagrams and Phase Transitions
  - Lattice Formulations for Quantum Computing







Can we use routinely collected electronic healthcare record (EHR) data to inform personalised antibiotic selection to improve clinical outcomes for people living with Cystic fibrosis?

Project: *Trailfinder CF Innovation Hub* (WP2.2)

Dr. Shahi Dost

- Cystic fibrosis (CF) is a life-limiting genetic condition marked by chronic lung infections, inflammation, and extensive antibiotic use, especially intravenous antibiotics for acute exacerbations.
- Optimal treatment strategies for exacerbations are not well understood.
- The main objectives of my post-doctoral research are to develop machine learning (ML) and mathematical models that can predict treatment strategies for ***people living with Cystic fibrosis*** (pwCF).

Research Questions:

1. What is the optimal selection of antibiotics treatment for pwCF to improve clinical outcomes using machine learning (AI) models?
2. Can we predict the outcome of antibiotics treatment using artificial intelligence (AI)?
3. Can we predict the antimicrobial resistance caused by cystic fibrosis bacteria (e.g., Pseudomonas aeruginosa, Staphylococcus aureus) strains using AI?

Trailfinder CF Innovation Hub
Funded by LifeArc and Cystic Fibrosis Trust

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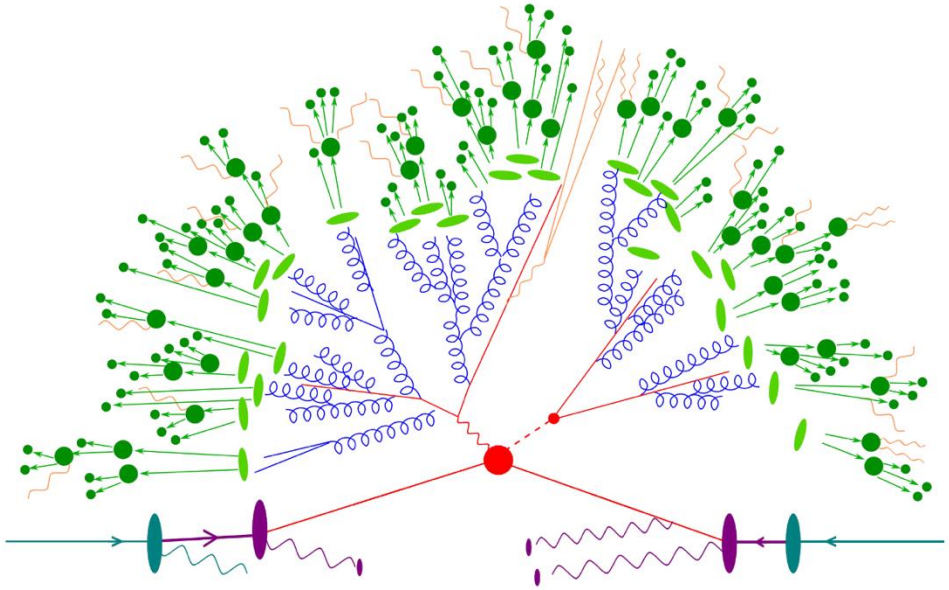
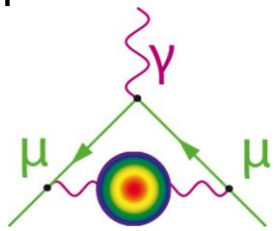
Lois Flower: Precision QED using Monte Carlo

- Develop Monte Carlo event generators
  - Software to simulate particle collisions
  - Perturbative methods used for the electroweak interactions and for high-energy QCD
  - Non-perturbative modelling used for low-energy QCD, producing measurable hadrons
- Beneficial to include effects at all orders to describe multiple-photon exchange and emission



A schematic picture of a high-energy electron-positron collision, as modelled by a Monte Carlo event generator

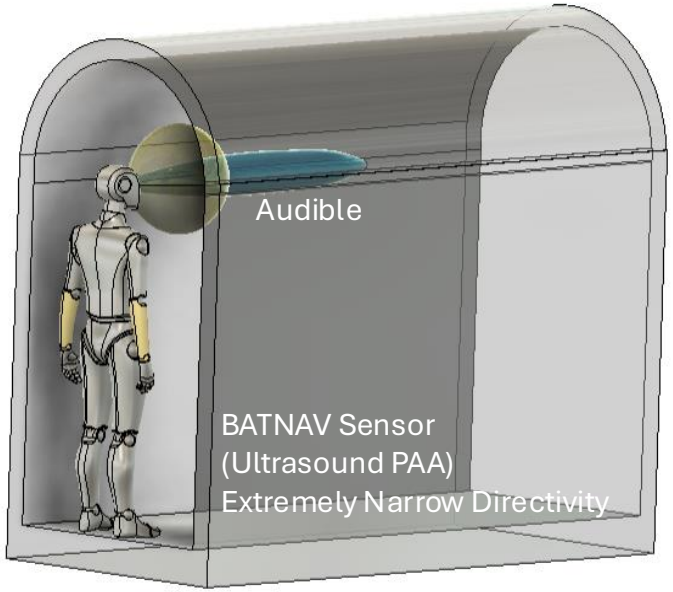
- How does this affect theoretical predictions for e.g. the muon anomalous magnetic moment?

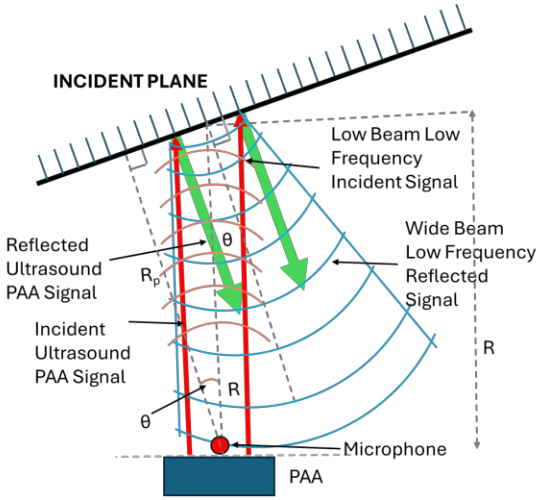


LEVERHULME TRUST

SHERPA

BATNAV SENSOR (PARAMETRIC ACOUSTIC ARRAY)



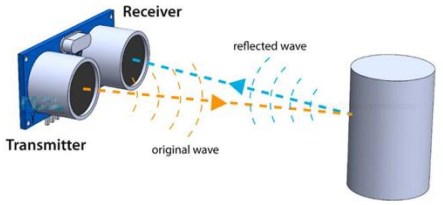


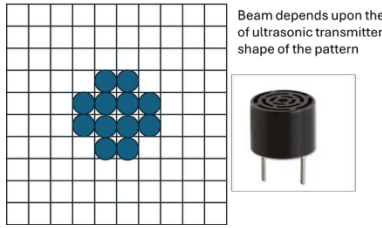
Overview

BATNAV sensing system incorporates a nonlinear ultrasonic acoustic technology to measure the distance of far located objects in critical conditions.

Key Work Done & Future Directions

- Review of literature on distance sensing using acoustics.
- Review of commercial and customized distance sensors using acoustic & ultrasonic waves.
- Broad design specifications and theoretical considerations of distance sensors using acoustic waves, ultrasonics (single sensor and parametric acoustic array (PAA))
- Broad design of different configurations of array of ultrasonic sensors suitable for PAA based BATNAV distance sensor
- Future directions is to simulate ultrasonic sensor in COMSOL, the propagation of ultrasonic waves in air as medium, its reflections and distance measurement in simulated environment in COMSOL.





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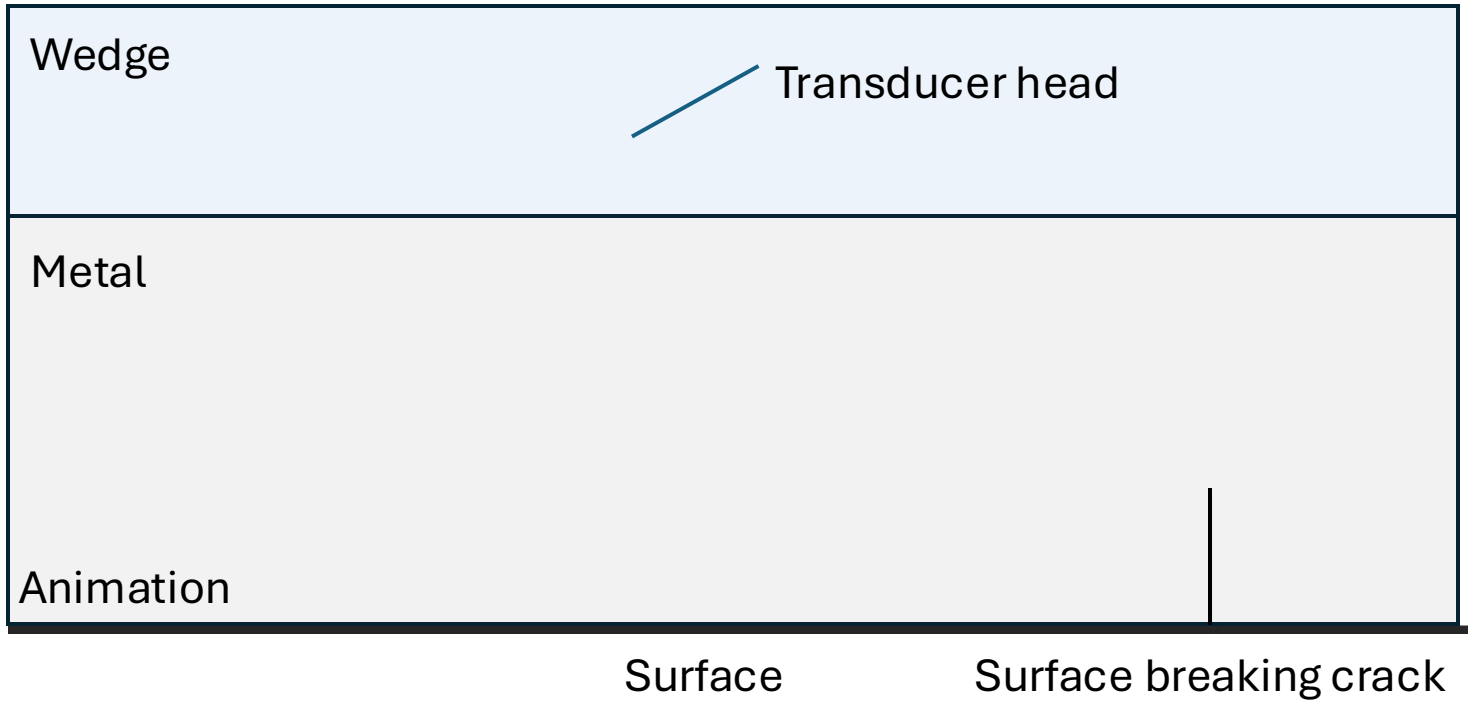
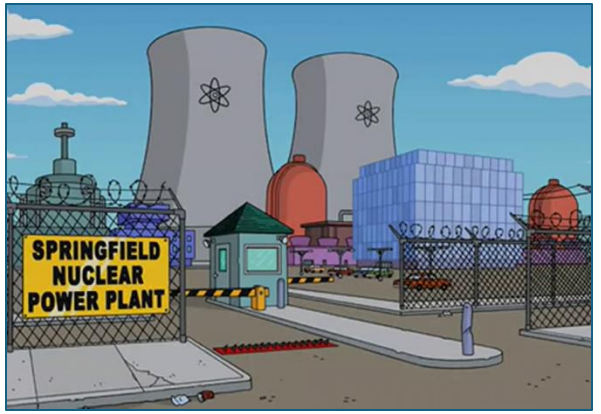
Project: MUSICA
PI: Stewart Haslinger
Funder: RCNDE

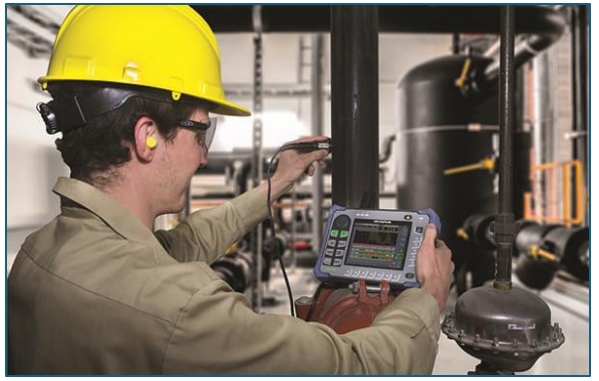
James Gaffney

- Cracks in nuclear power stations are bad news
- Ultrasound techniques are used to find, characterise and size cracks
- I simulate ultrasound to build a database to train an ML algorithm to sizes surface breaking cracks



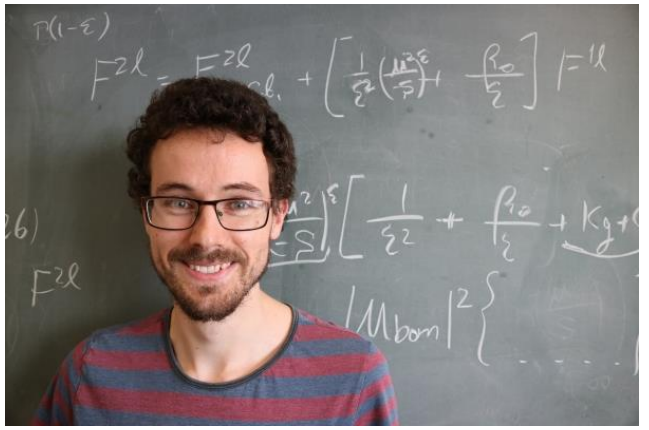


https://www.energy.gov/ne/articles/7-things-simpsons-got-wrong-about-nuclear



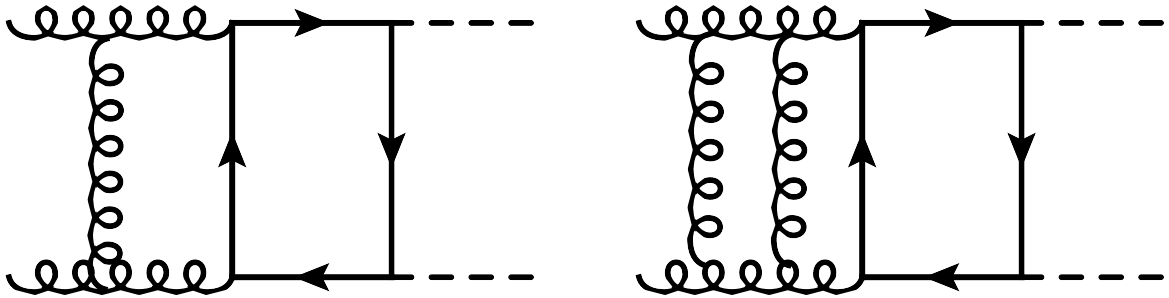
https://www.powermag.com/ultrasonic-testing-for-the-power-generation-industry/

Josh Davies (TP)



Research Activities:

- Multi-loop QCD and EW amplitudes
  - AKA "Computations for LHC physics"
    - Higgs pair production at 2,3 loops
    - Deep-Inelastic Scattering at 3,4 loops



- Large-scale Computer Algebra problems
  - Integration-by-parts Reduction
  - Computer Algebra on HPC systems

- Development of Computer Algebra software
  - FORM: https://github.com/form-dev/form
  - Developers' Workshop 2025 (Liverpool)

Jeremy Paltrinieri

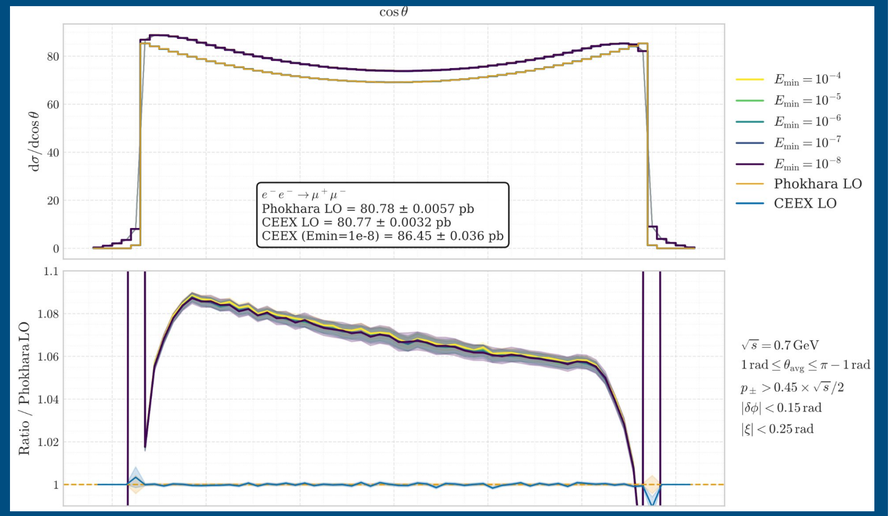
LEVERHULME TRUST

Motivation from the muon anomalous magnetic moment determination (g-2)

Monte-Carlo Studies for e+e- annihilation processes:

- **Within the KLOE experiment collaboration:** measurement of ee->pipi cross-section needs appropriate Monte-Carlo generators
- **Within RadioMonteCarlow2:** systematic studies of Monte-Carlo generators for relevant low-energy processes

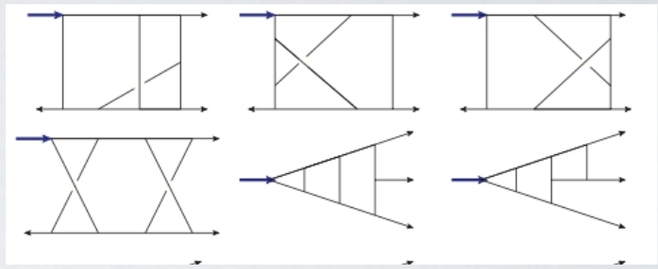
Resummation of soft-photon effects in QED processes: theory development and implementation



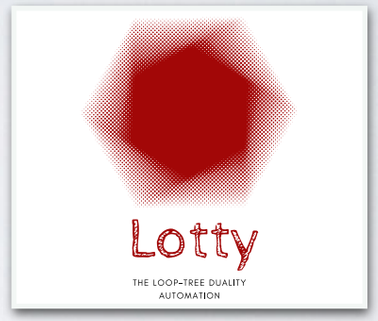
William J. Torres Bobadilla

Research interests

- Efficient calculation of phenomenological observables
  —> High energies ($pp \to H$ + jets @ N3LO)
  —> Mixed QCD/EW corrections ($pp \to HH$ @ N3LO)



- Mathematical properties of multi-loop scattering amplitudes
  —> Unitarity & analyticity of S-matrix
  —> Loop-tree duality formulation

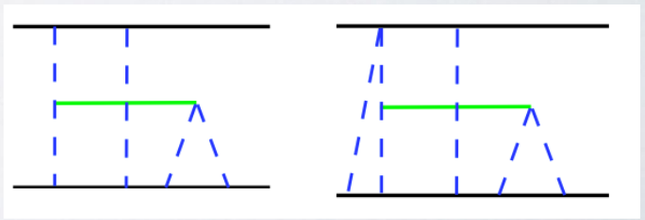


- Monte Carlo generator for low-energy physics @ NNLO
  —> Physics of $(g-2)_\mu$ via $e^+e^- \to$ hadrons

Main framework :: scattering amplitudes

- Effective Field Theory approach to General Relativity
  → Post-Newtonian corrections to the Newtonian potential

- Dark Matter Searches
  → Loop integrals arising in low-energy effective interactions



- Neural Network Techniques
  → Fast exploration of mathematical and physical structures (e.g., bootstrapping of amplitudes)

Tetiana Kozynets

Goes by "**Tania**"

Part of the QuMAP Quantum Materials and Astroparticle Physics group

(PI: Juri Smirnov)

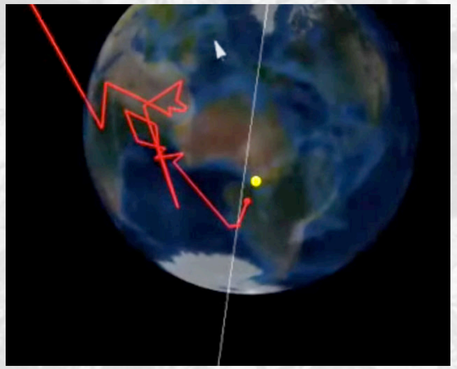
Research revolves around **dark matter**

Selected research directions

QUEST DMC

- Direct **dark matter detection** using superfluid ^{3}He

- Development of dark matter propagation codes (diffusion through the Earth)



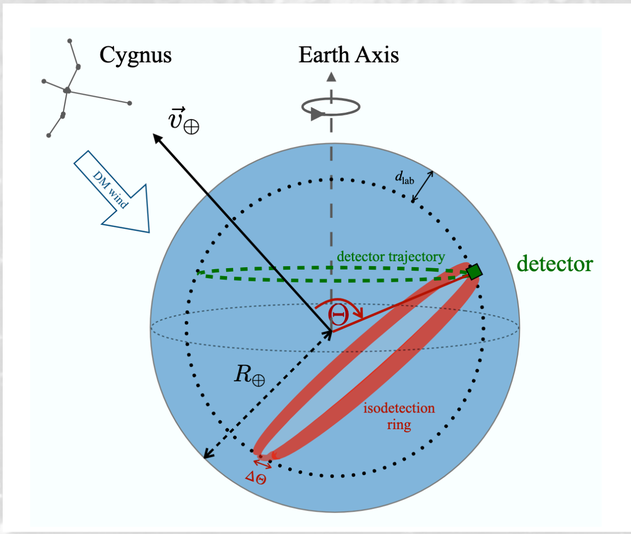


Fig. from arXiv:2507.00344

- Prediction of daily modulation signals due to dark matter wind anisotropy

Nick Rekuski

- Nick is a pure mathematician working in algebraic geometry. Algebraic geometry is the study of spaces defined by the vanishing of polynomial equations.
- His work focuses on the existence and nonexistence of stable vector bundles on these spaces. Such results have subtle geometric consequences and connections to other fields (such as string theory).
- In recent joint work, he gave such a nonexistence result on some spaces of interest called Calabi-Yau threefolds. This has led to significant progress on a conjecture from 2004.

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ANY QUESTIONS?

Dan Colquitt
d.colquitt@liverpool.ac.uk

Thomas Teubner
teubner@liverpool.ac.uk