

## NUF UKAEA-MRF Facility Experiments:

Investigation of proton-irradiation induced damage in POCO graphite

Eric Jiang<sup>1</sup>, George Lolov<sup>2</sup>, Kavin Ammigan<sup>2</sup>, Frederique Pellemoine<sup>2</sup>, Patrick Hurh<sup>2</sup>, Dong Liu<sup>1\*</sup>

<sup>1</sup> Experimental Mechanics of Advanced Materials, School of Physics, University of Bristol, Bristol, BS8 1TL, UK

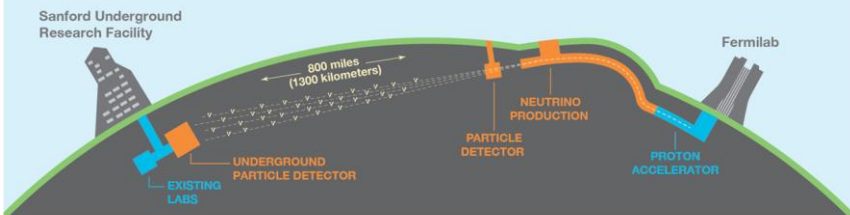
<sup>2</sup> Target Systems Department, Fermi National Accelerator Laboratory, Batavia IL, 60510-5011, USA

Email: [Dong.Liu@bristol.ac.uk](mailto:Dong.Liu@bristol.ac.uk)

## Background

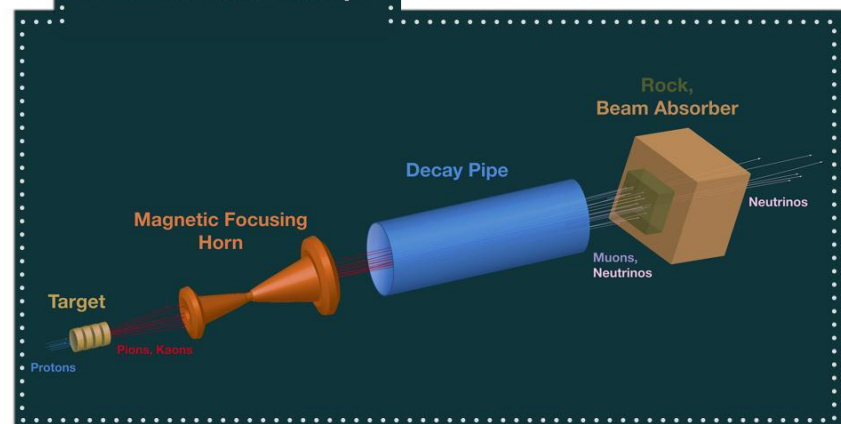
- Student on this project: Eric Jiang (2<sup>nd</sup> year; Funded by the US Fermi National Accelerator Laboratory)
- Why POCO graphite?

In collaboration with FermiLab (U.S.) and RaDIATE.



The schematic of Deep Underground Neutrino Experiment (DUNE)

## Neutrino Beam Recipe



- \$1.5bn Long Baseline Neutrino Facility (LBNF)
- UK are expected to contribute ~\$500 m to Dune and LBNF

## Experimental Mechanics of Advanced Materials Research Group

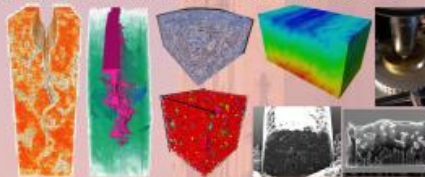


Dr. Dong (Lilly) LIU

### Nuclear Graphite

These are graphite composites with complex microstructures across multiple length-scales. They offer excellent thermo-mechanical, neutronic and pion production properties and play a vital role in nuclear reactors and particle accelerators worldwide. We study these materials via a range of techniques including high resolution X-ray tomography at high temperature, synchrotron X-ray diffraction, neutron diffraction, electron microscopy (FIB-SEM, TEM and EBSD etc), micro-/macro-mechanical testing, digital image/volume correlation and micro-Raman spectroscopy to gain a mechanistic understanding of their microstructural-property relationships across many length scales under irradiated and un-irradiated conditions.

Researchers: Eric Jiang, Eleanor White, Aimee Coleman



### TRISO Nuclear Fuel

TRISO particles contain a kernel of uranium-based material coated in protective carbon and silicon carbide for strength and to stop radioactive products escaping. These ~1 mm particles are packed into a ceramic or graphite pellet to fuel high temperature reactors. We study the structure, residual stresses and thermal/mechanical properties of these particles and pellets using X-ray tomography, electron microscopy, micromechanical testing, Raman spectroscopy, and transient thermoreflectance techniques.

Researchers: Haiqi Huang, Dr Alex Leide

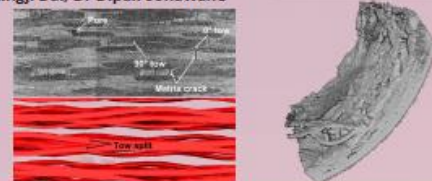


Dr Dong (Lilly) Liu, Dr Alex Leide, Dr Dipali Sonawane, Paul Fornas-Kretzler, Sarah Mann, Eric Jiang, Aimee Coleman, Haiqi Huang, Guanjie Yuan, Bingyu Liu, Eleanor White, Mingji Dai

### Ceramic-Matrix Composites

CMCs consist of ceramic fibres embedded in a ceramic matrix, offering excellent high-temperature performance and improved fracture toughness compared to monolithic ceramics and metals. We use *in situ* high temperature tomography, digital volume correlation, nanoindentation, high-temperature and micro-Raman spectroscopy to investigate their mechanical behaviours in aerospace and nuclear applications.

Researchers: Paul Fornas-Kretzler, Guanjie Yuan, Bingyu Liu, Mingji Dai, Dr Dipali Sonawane



### MAX Phases

MAX-Phases are layered carbides, nitrides and borides with unique and compelling properties suitable for extreme environments such as radiation resistant nuclear reactor parts. The key to harnessing these materials is to understand their microstructural changes as they deform. We use *in-situ* neutron diffraction to investigate their mechanical behaviour.

Researcher: Aimee Coleman



### Neutron Detectors

Neutron detectors are needed for a large range of applications, from materials science to the nuclear industry.

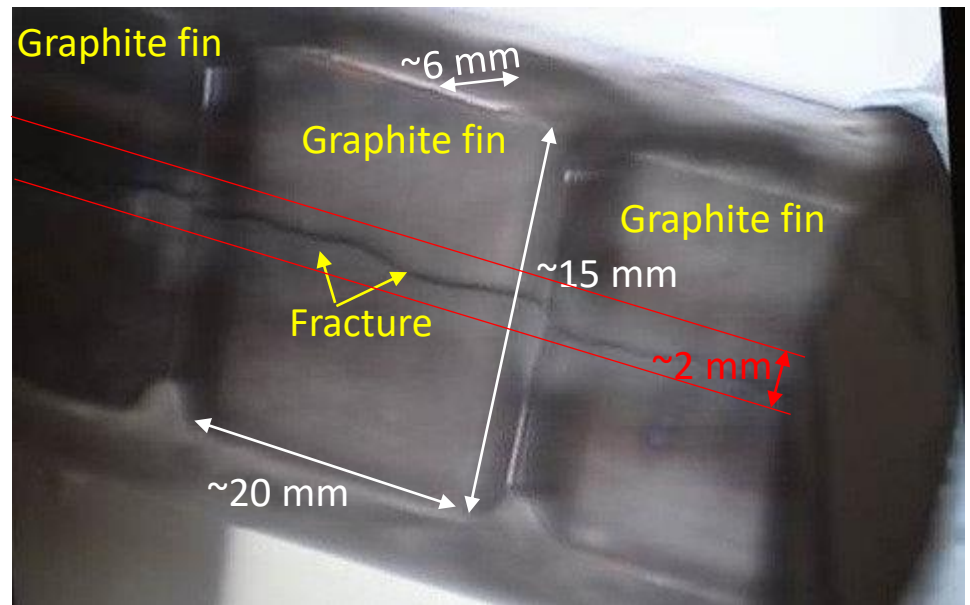
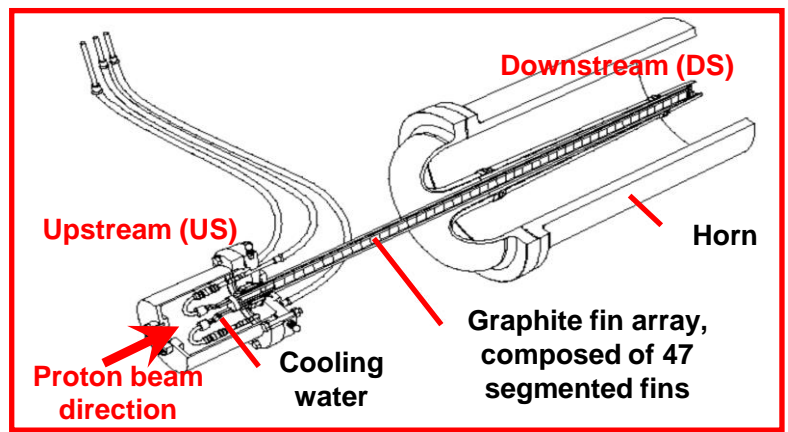
Novel materials including nanoparticles are being developed and investigated for the next generation of scintillation-based neutron detectors.

Researcher: Sarah Mann



### Background

Aim: Study the degradation in terms of microstructure, physical and thermo-mechanical properties of POCO graphite





## UKAEA (Culham) MRF:

- Receiving and storage of hot samples:
  - Proton irradiated - hot materials beyond university limits
  - Shipped from the USA PNNL to Materials Research Facility, UKAEA (Culham)
- Experiments (two rounds about 14 days in total):
  - Micro-Raman spectroscopy
  - FIB-tomography
  - TEM foils liftouts for post analysis in Bristol
- Key outcome:
  - Overall irradiation damage on the graphite crystallites at various distances away from the beam centre
  - Porosity evolution
  - Successful TEM samples
- Follow-up experiments:
  - TEM analysis
  - Synchrotron beamline diffraction experiments at RAL
  - Comparison with other types of fine grain graphite

### Materials Research Facility

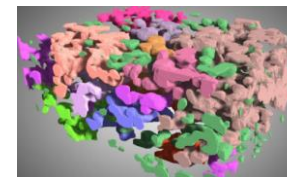


Micro-Raman spectroscopy at MRF



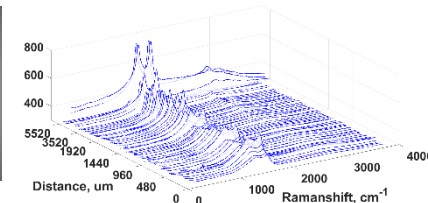
FEI Helios Nanolab 600i  
Dualbeam at MRF

### Image segmentation



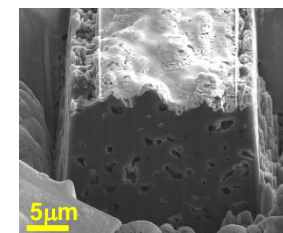
Porosity segmentation  
generated by deep learning  
method (30x17x23 $\mu$ m)

### Micro-Raman spectroscopy

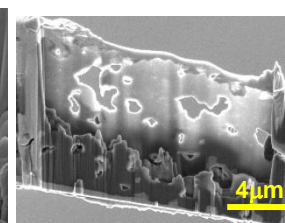


Raman line-scans and mapping

### FIB-tomography and TEM foil liftout



FIB tomography of  
irradiated POCO graphite



TEM foil of irradiated  
POCO graphite