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Recent Advances in Positron Emission Particle Tracking

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School of Chemical Engineering
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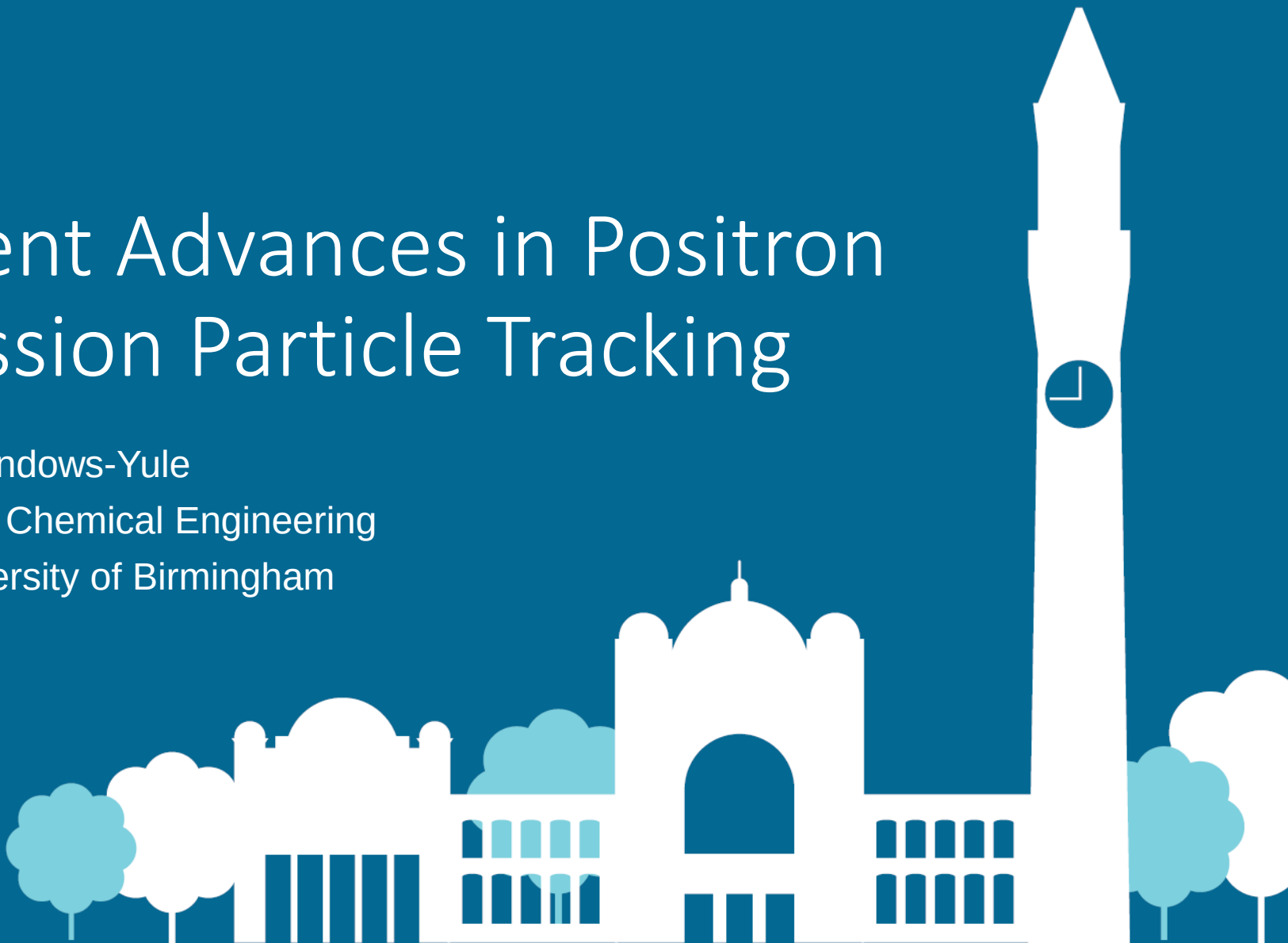

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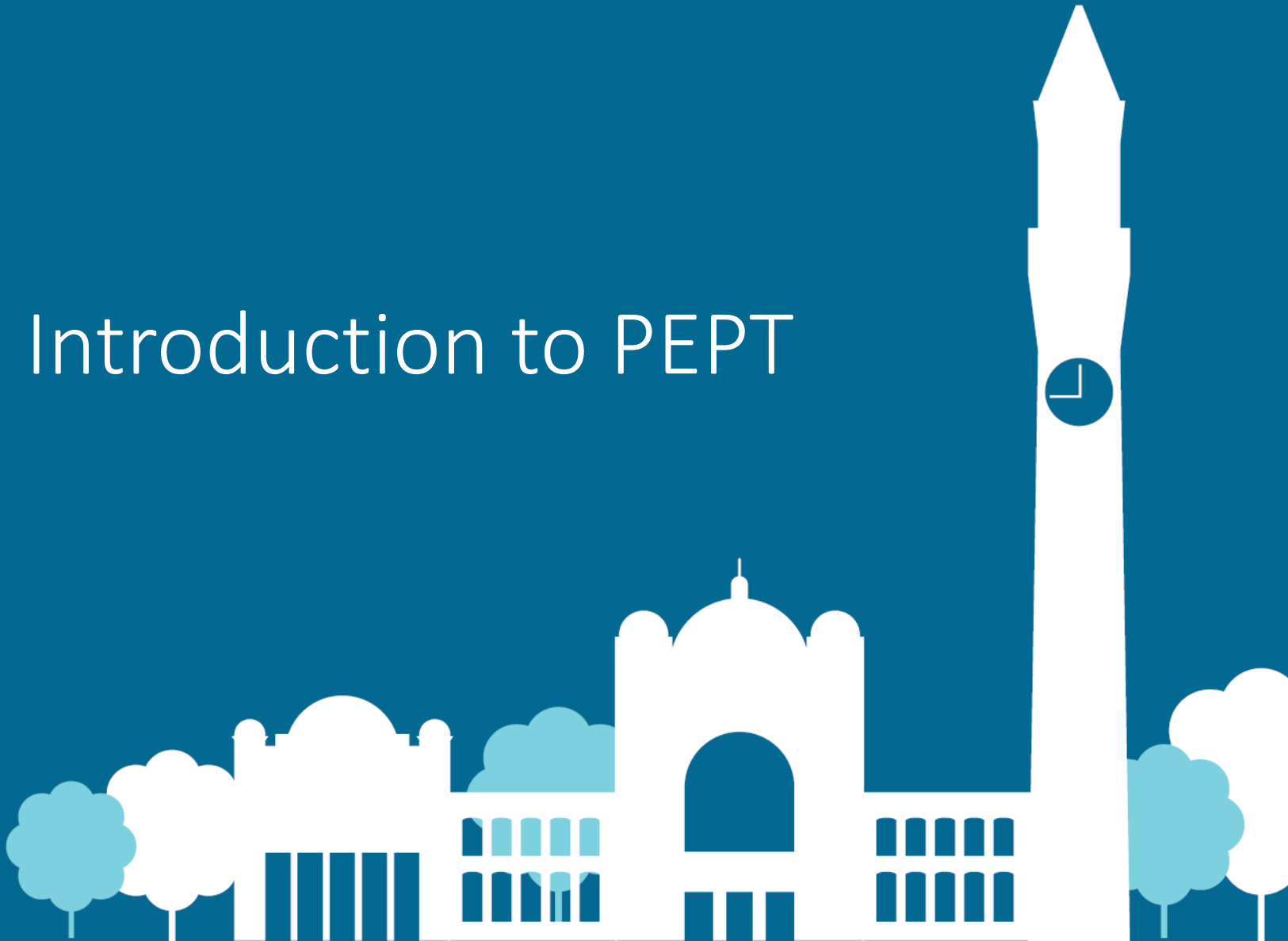
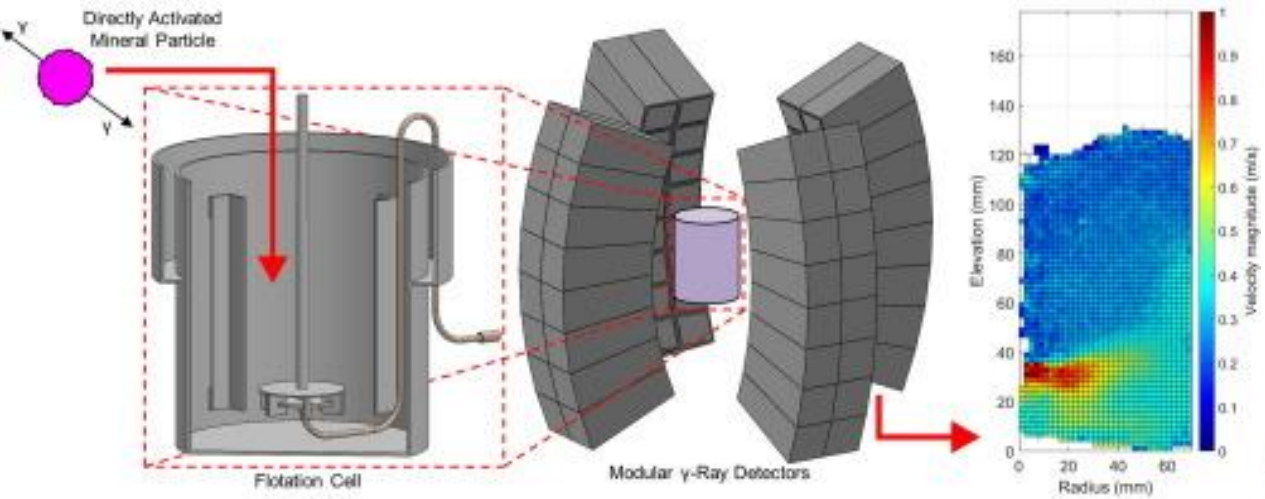
I. An Introduction to PEPT



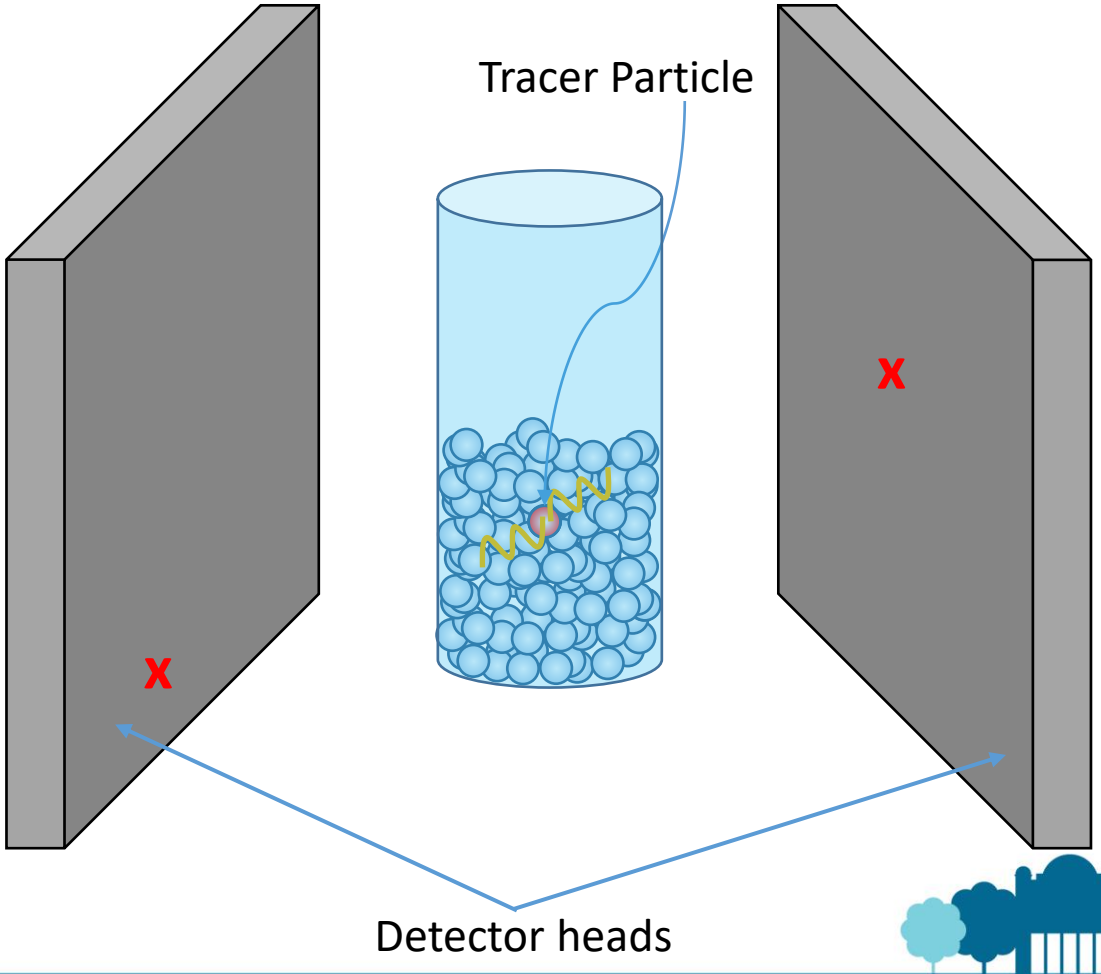
What is PEPT?

- Uses highly-penetrating gamma radiation to **directly track** the three-dimensional motion of particles through particulate, fluid and multiphase systems, with high temporal and spatial resolution.
- In essence, it allows us to **'see inside' opaque systems**.



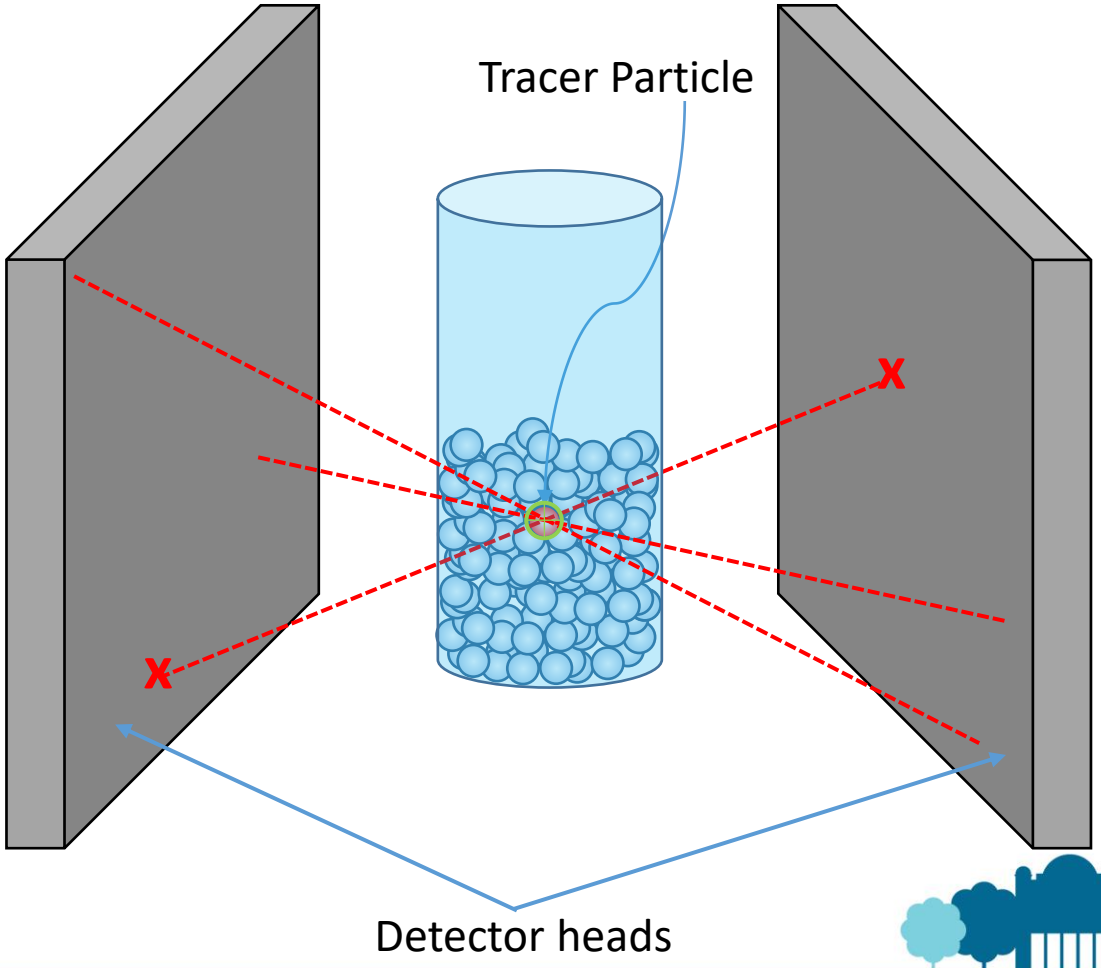
An example of PEPT imaging for an industrial system

How does it work?

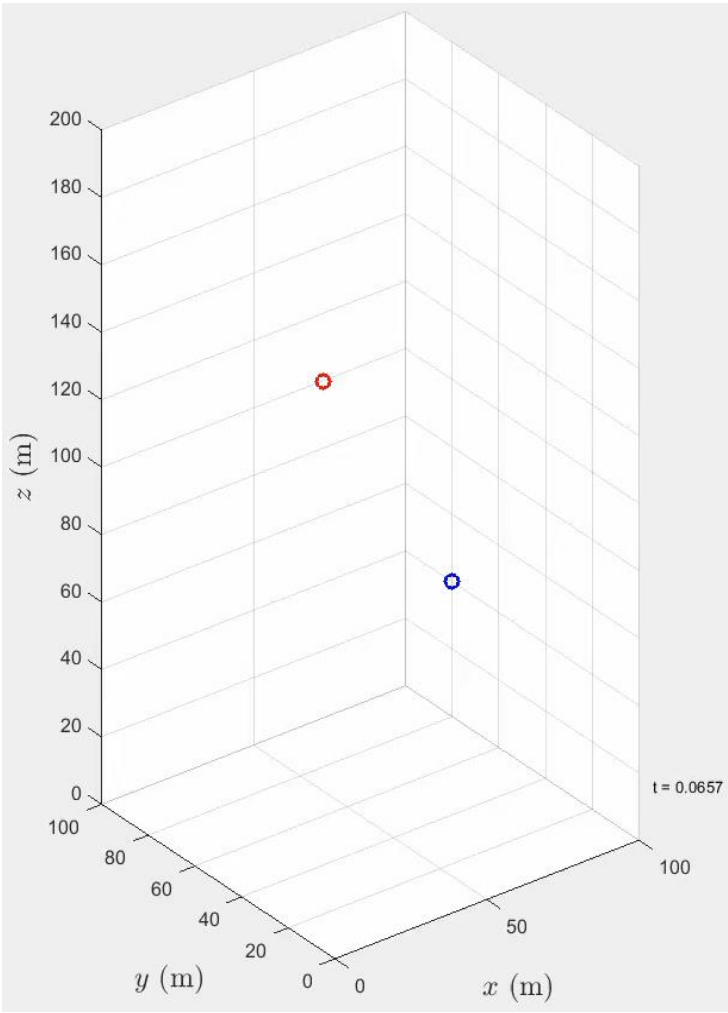


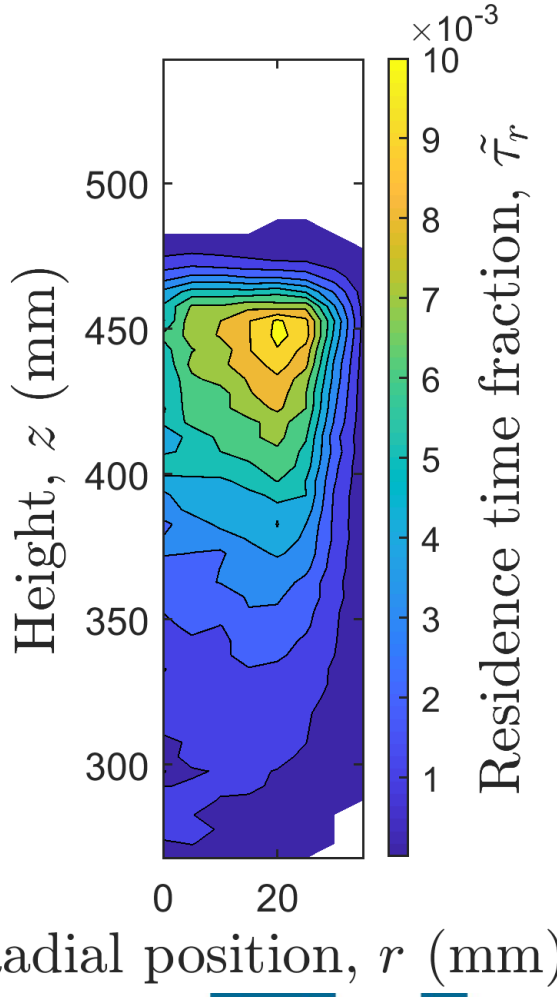
Windows-Yule, C. R. K., Seville, J. P. K., Ingram, A., & Parker, D. J. (2020). Positron Emission Particle Tracking of Granular Flows. *Annual Review of Chemical and Biomolecular Engineering*, *11*.

How does it work?

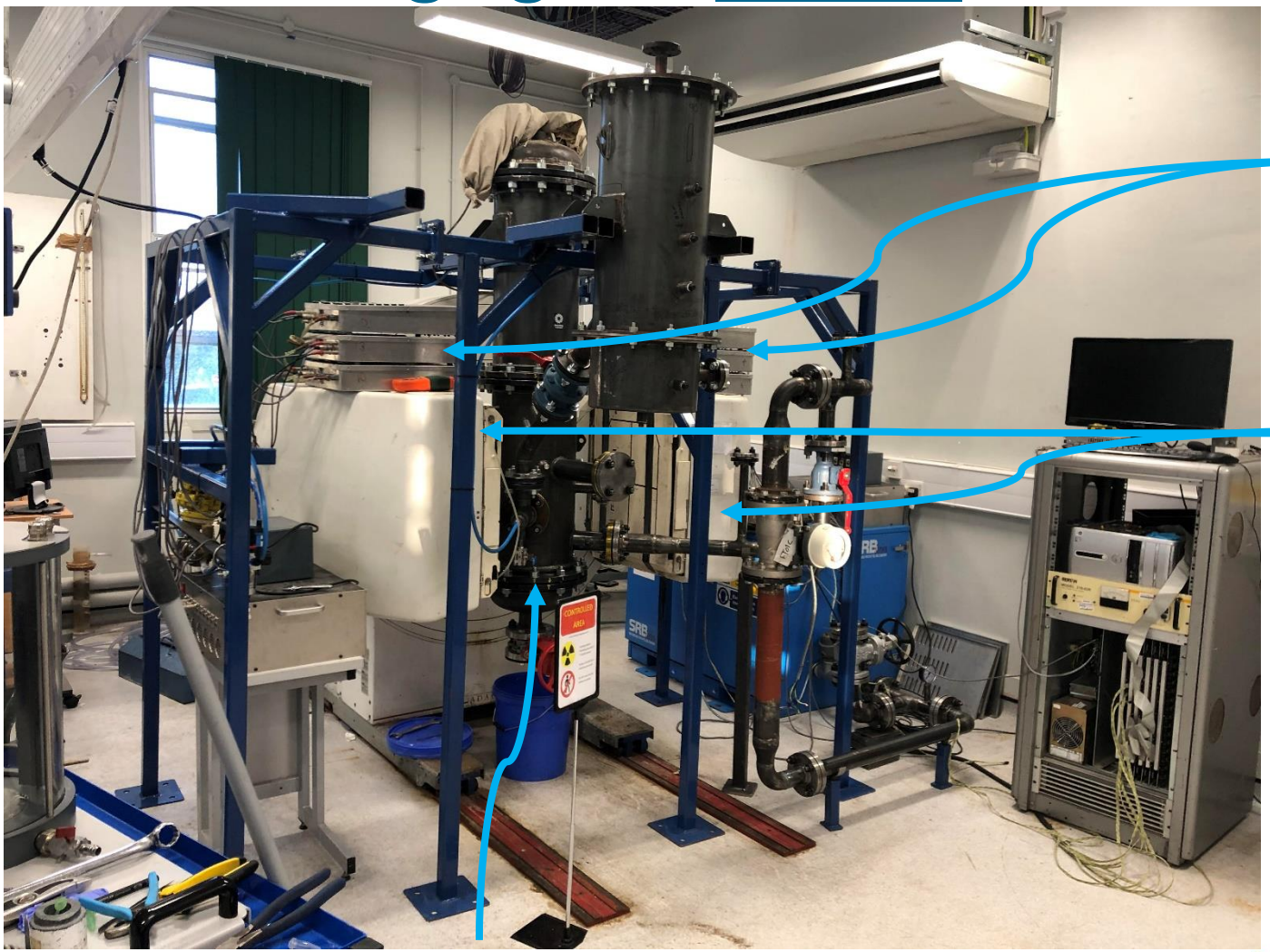


Example: PEPT imaging of a fluidised bed





PEPT Imaging of a serious Fluidised Bed



Modular cameras provide additional, flexible imaging area

Main ADAC camera heads

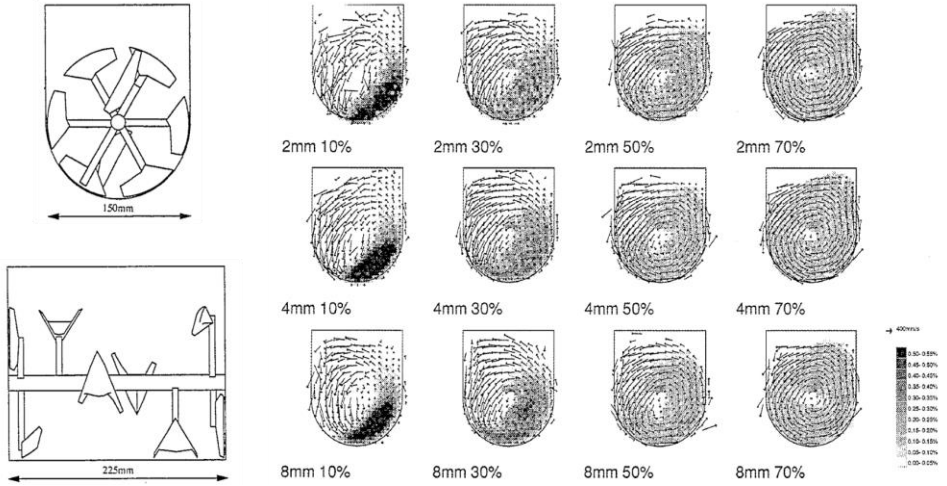
Large, opaque vessel ($D = 300\text{mm}, H > 1\text{m}$)

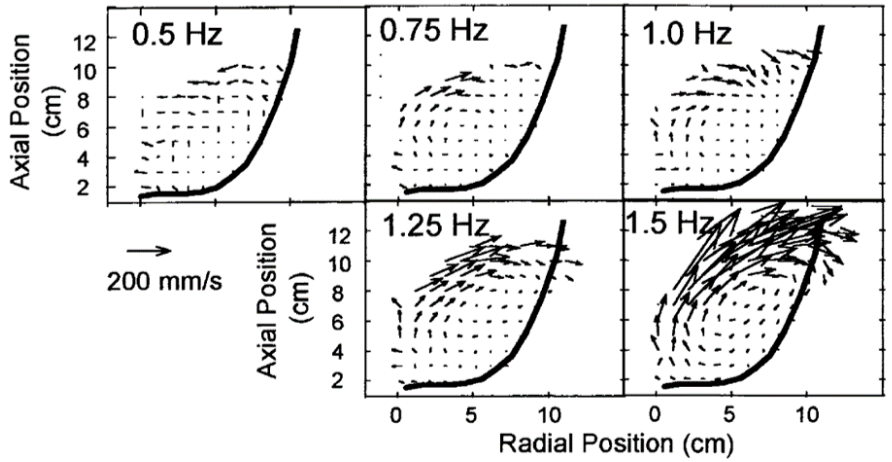
Solid steel walls

Why use PEPT?

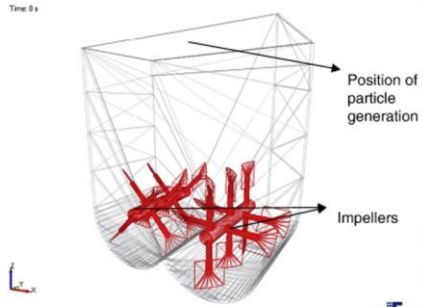
- Offers a unique set of abilities not offered by any other technique
- Can image a wide range of industrial and scientific systems
- Can extract a wide range of detailed, three-dimensional information from a system
  - → A highly valuable tool for the **validation of numerical simulations**

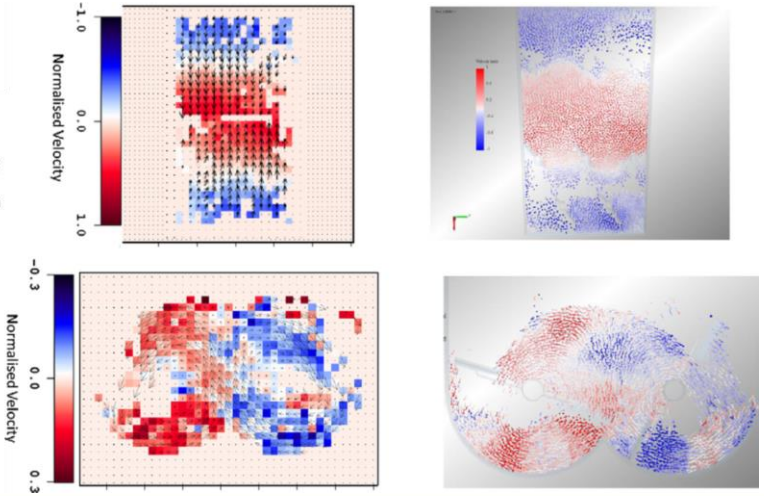
A wide range of industrial & scientific systems

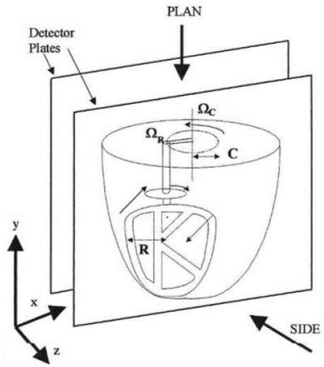


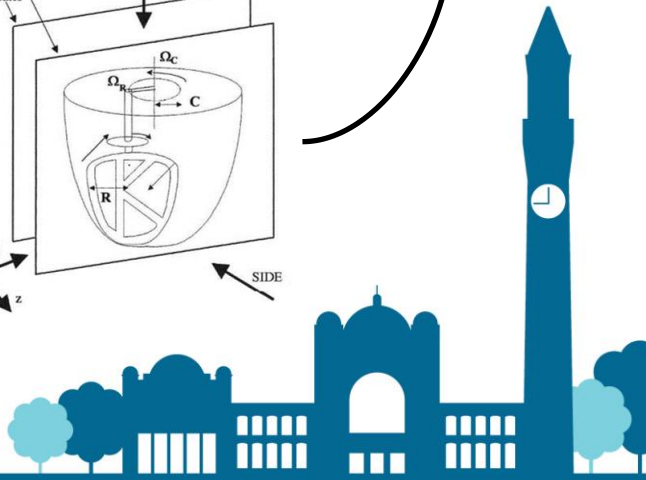


Industrial Mixers



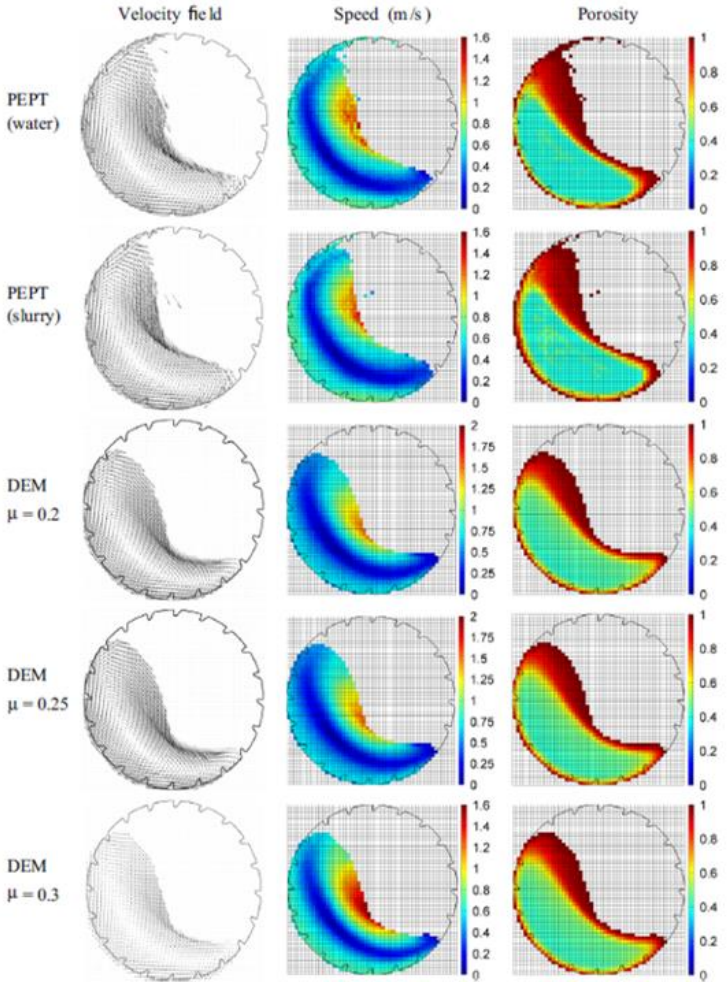


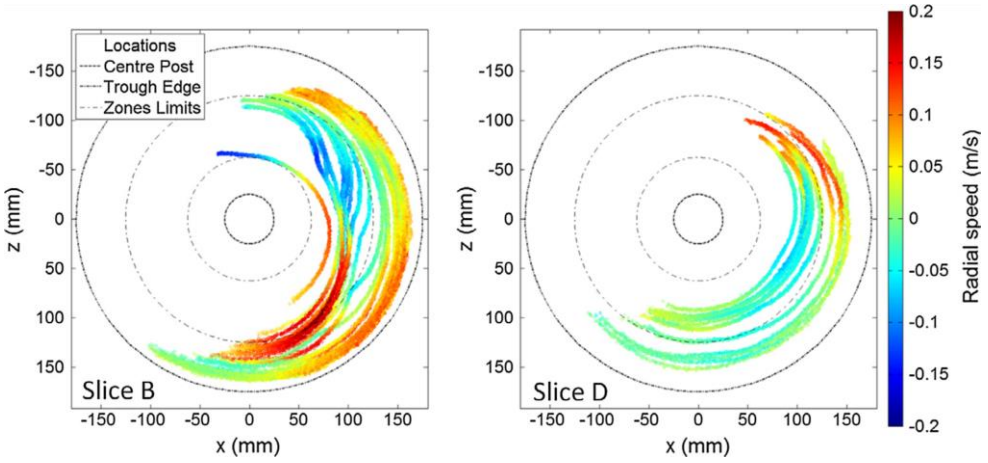




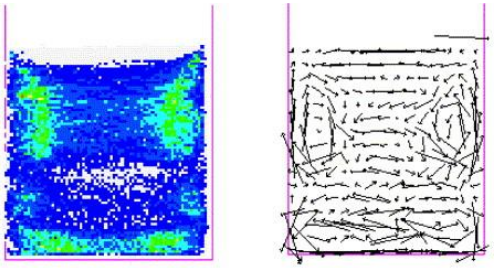
Windows-Yule, C. R. K., Nicuşan, A.L., Herald, M. T., Manger, S. & Parker, D.J., *PEPT, a Comprehensive Guide*, IoP eBooks, to be published Dec. 2021

A wide range of industrial & scientific systems

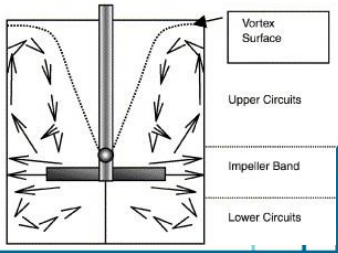




Spiral mineral concentrators



Mills



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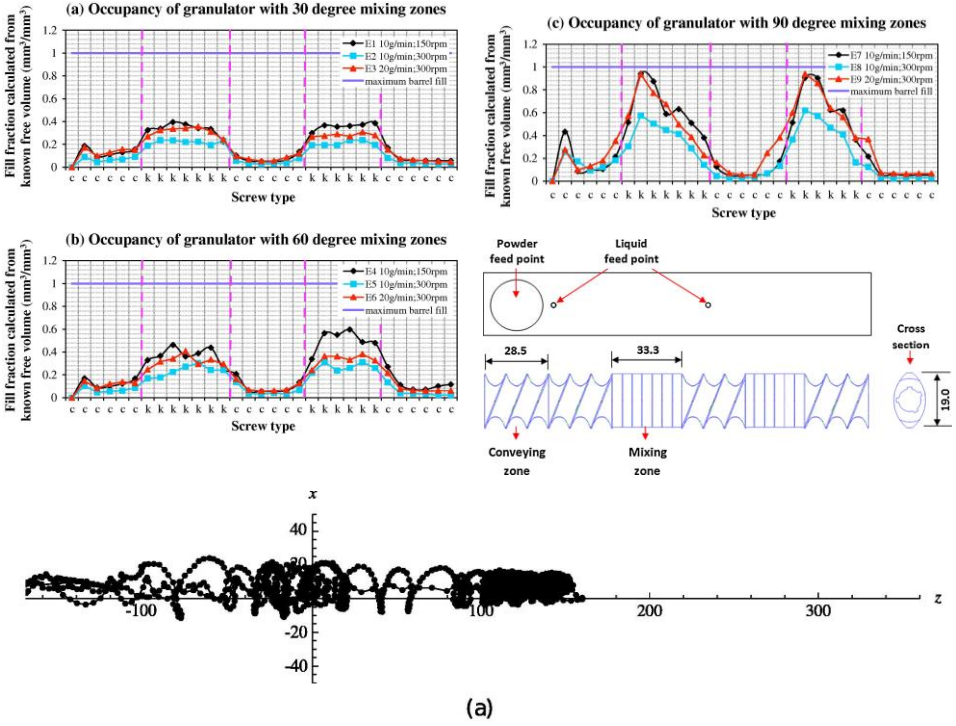
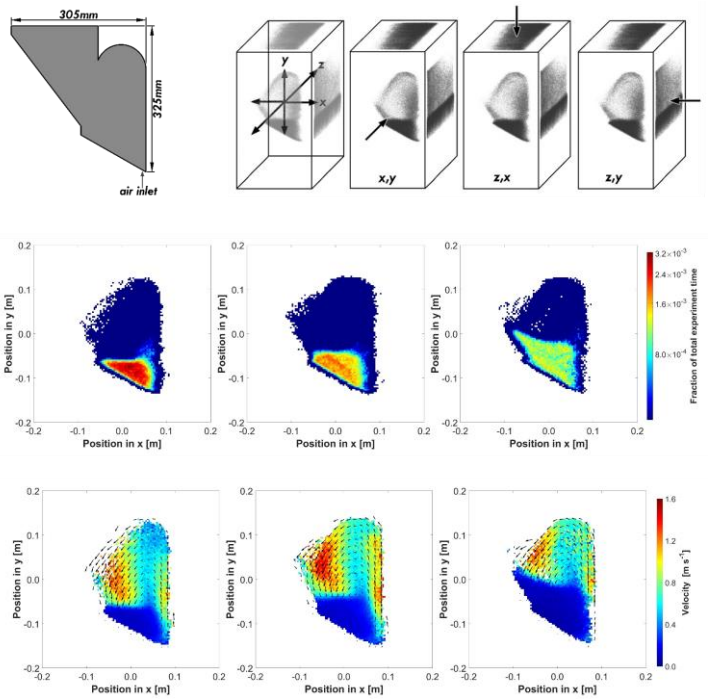
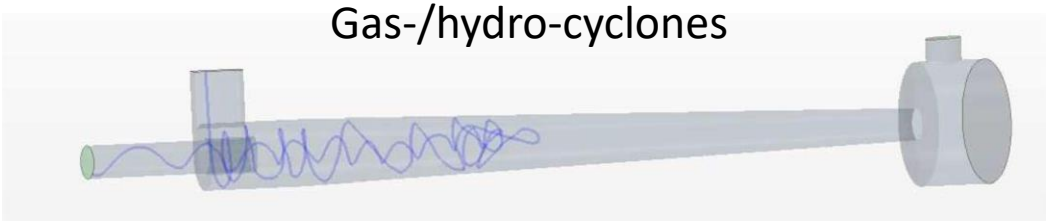
A wide range of industrial & scientific systems

Twin screw granulators





Gas-/hydro-cyclones



Coffee roasters

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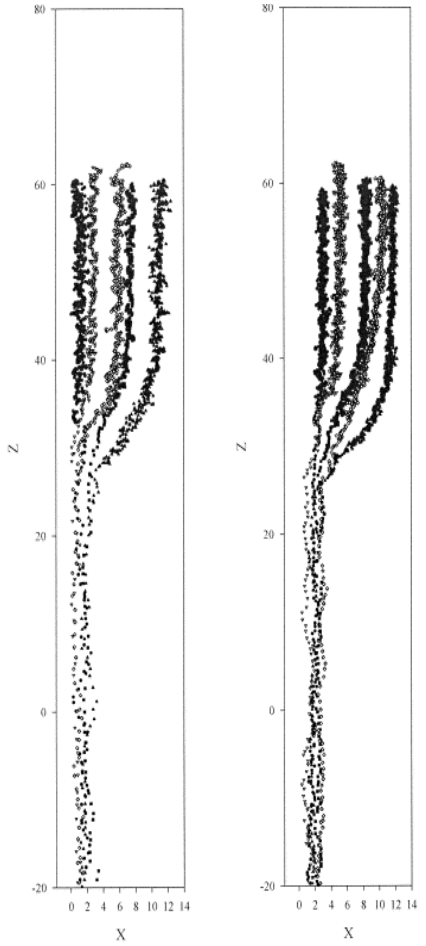
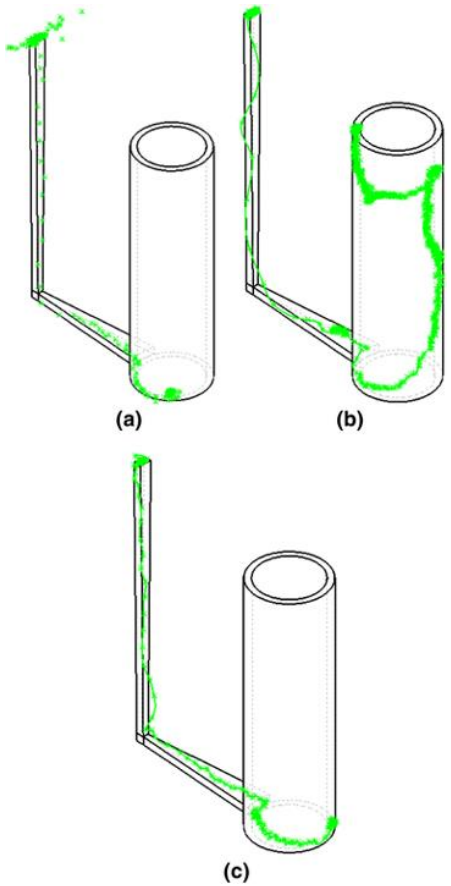
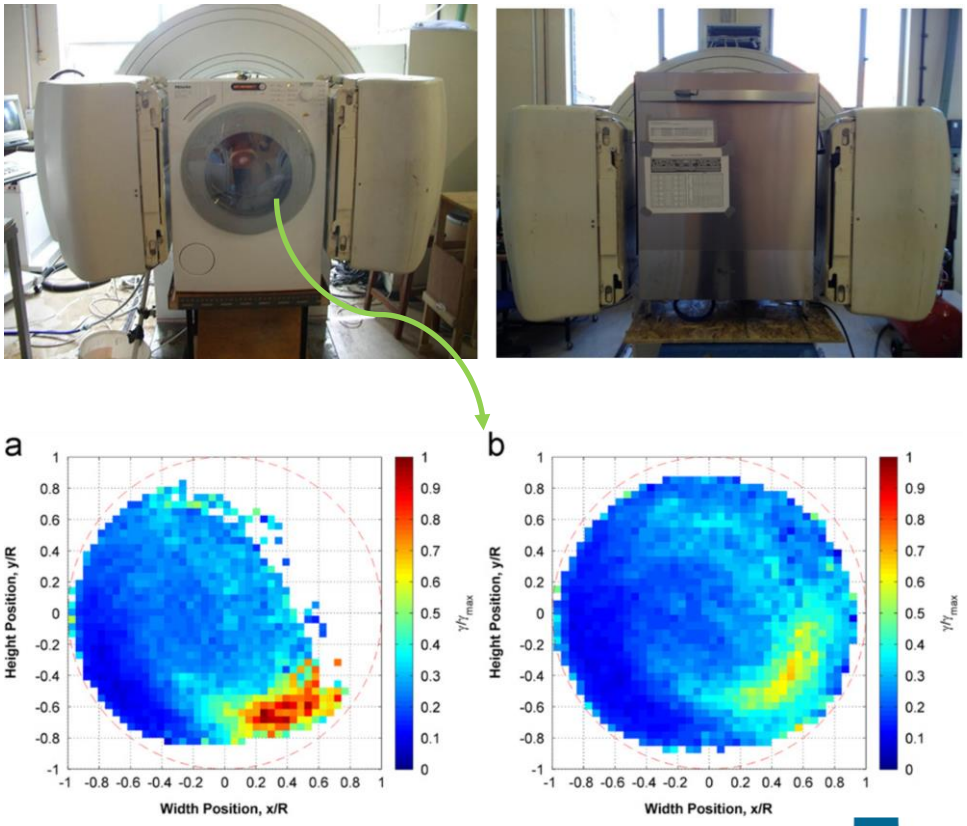
A wide range of industrial & scientific systems



Extruders



Metal casting



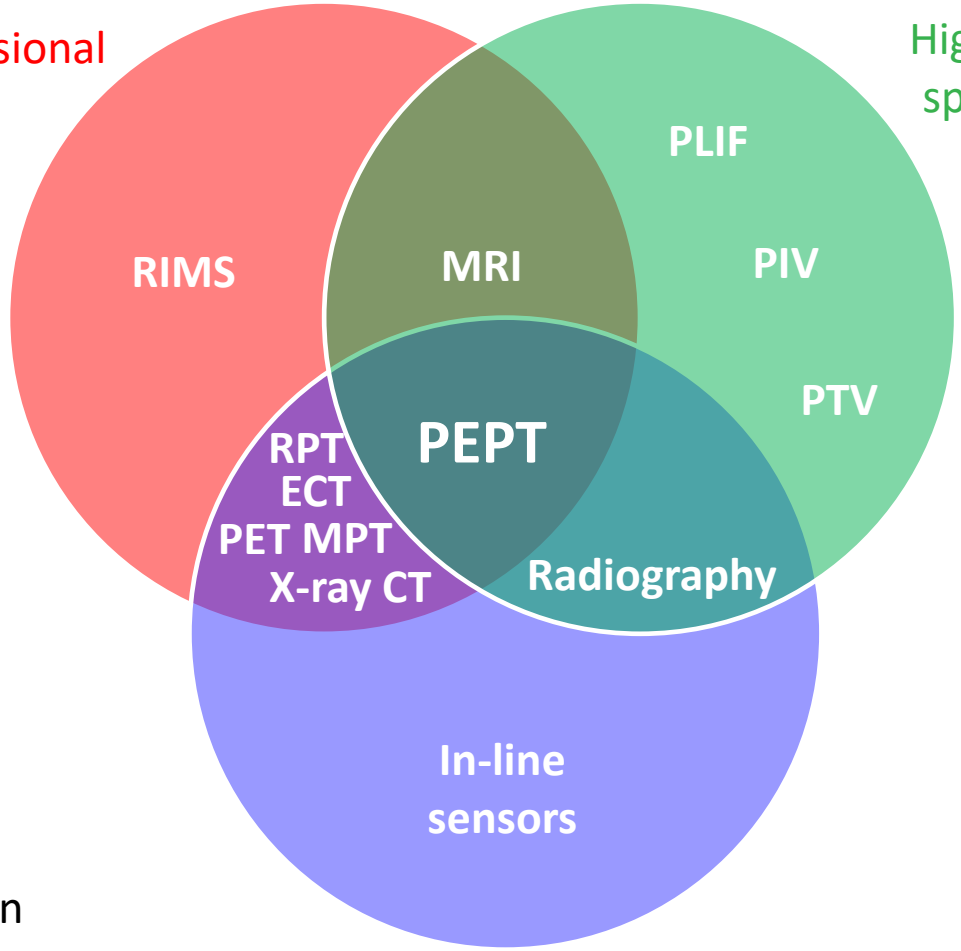
Domestic systems

Windows-Yule, C. R. K., Nicuşan, A.L., Herald, M. T., Manger, S. & Parker, D.J., *PEPT, a Comprehensive Guide*, IoP eBooks, to be published Dec. 2021

A unique set of abilities

Full, three-dimensional imaging

High temporal and spatial resolution



(Few limitations on size/materials)

Capable of imaging real industrial systems

Horses for courses

- So PEPT is **the best imaging technique**?
- Honest answer: it depends on what you are interested in
- All imaging techniques possess their own unique strengths and weaknesses…

Horses for courses

	PEPT	PTV	PIV	PI	X-ray	CT	SPECT	PET	ECT	MRI	RIMS	CARPT	MPT
Temporal resolution													
Spatial resolution													
3D imaging?													
Opaque systems?													
Large systems?													
Limitations on materials?													
Transient information?													
Collision information?													
Orientation information?													
Stress information?													
Detailed calibration?													
Non-invasive?													
Lagrangian information?													
Cost													

A closer look – PEPT's big strengths and weaknesses

- In short, PEPT is particularly valuable for imaging systems which are:
  - Three-dimensional
  - Optically opaque
    - Including steel-clad systems where CT/MRI struggle
  - Large
  - Fast-moving
  - Require high-resolution imaging

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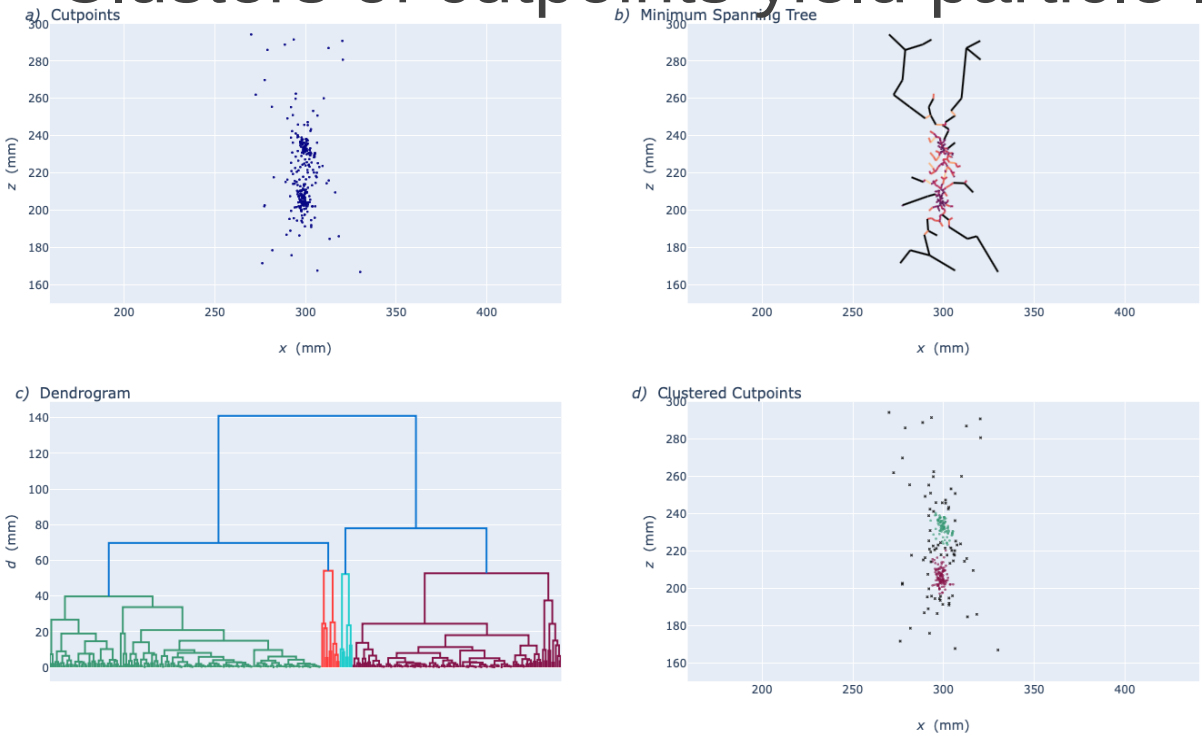
II. Recent Advances

Please note this will very much be a “flying overview” – each topic discussed here has previously been the focus of an **entire talk**!

If anything I mention is of interest, please feel free to ask questions or drop me an email after the talk.

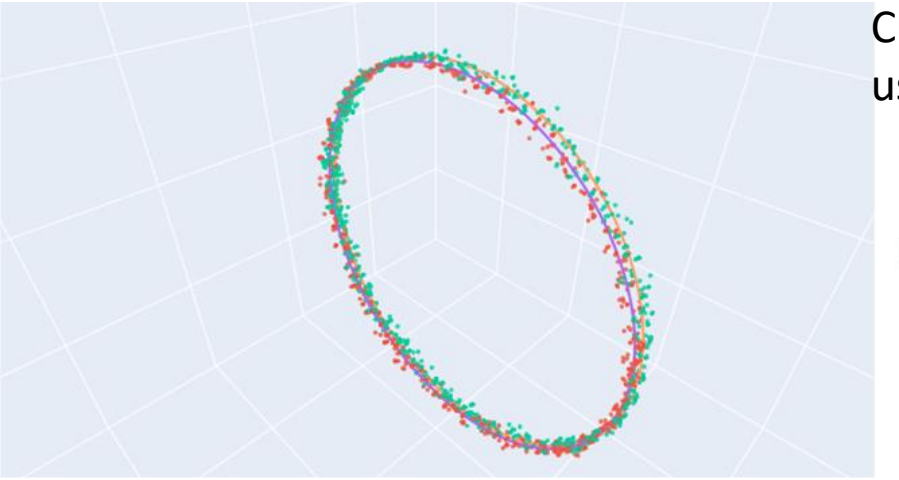
Using Machine Learning to track more particles, more accurately

- Using HDBSCAN clustering algorithm
- Converts lines of response to “cutpoints”
- Clusters of cutpoints yield particle locations



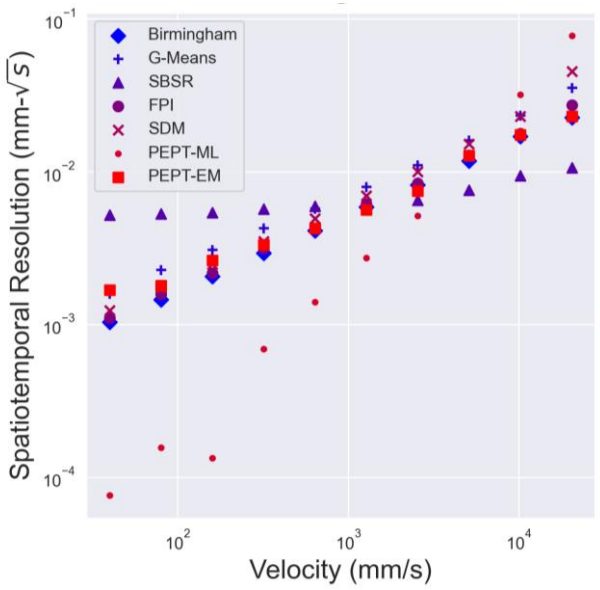
Nicuşan, A. L., and C. R. K. Windows-Yule. "Positron emission particle tracking using machine learning." *Review of Scientific Instruments* 91.1 (2020): 013329.

Using Machine Learning to track more particles, more accurately



Two particles on a rotating arm

Current most commonly-used method, using 250 lines of response per sample

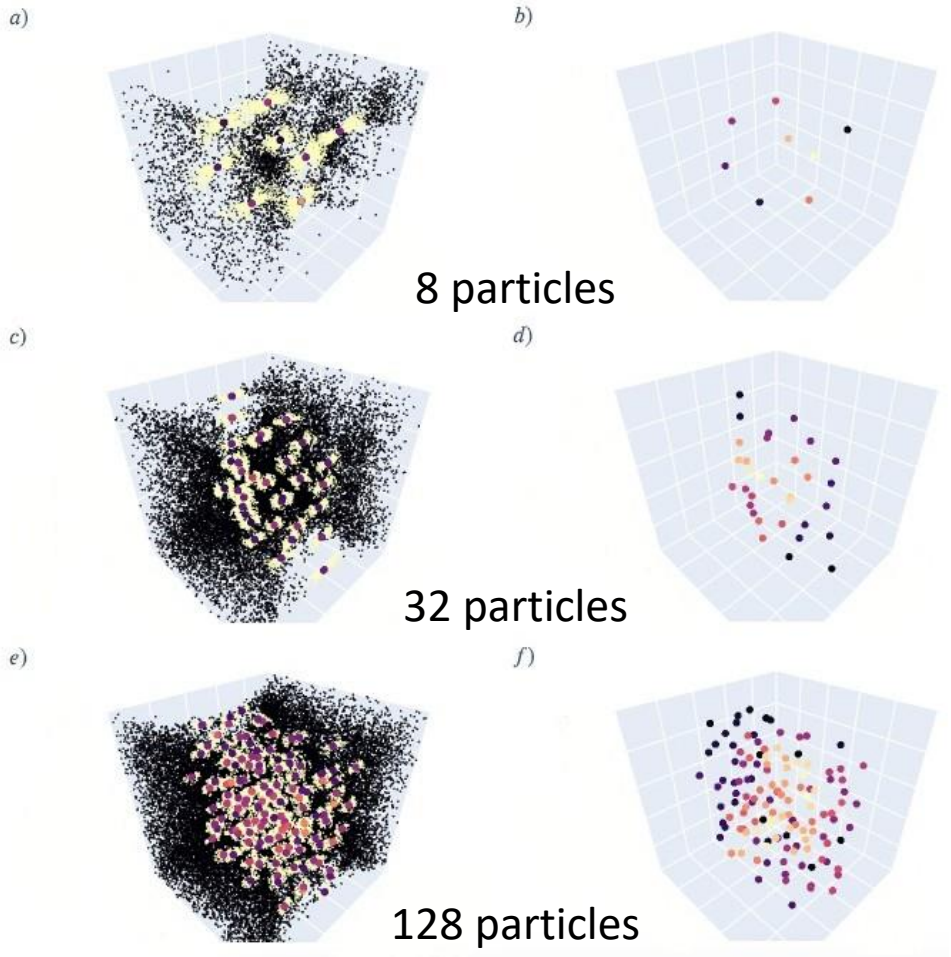


Highest spatiotemporal resolution of **any** current algorithm for low/moderate velocities

PEPT-ML, using **100** lines of reponse per sample

Nicuşan, A. L., and C. R. K. Windows-Yule. "Positron emission particle tracking using machine learning." *Review of Scientific Instruments* 91.1 (2020): 013329.

Using Machine Learning to track more particles, more accurately

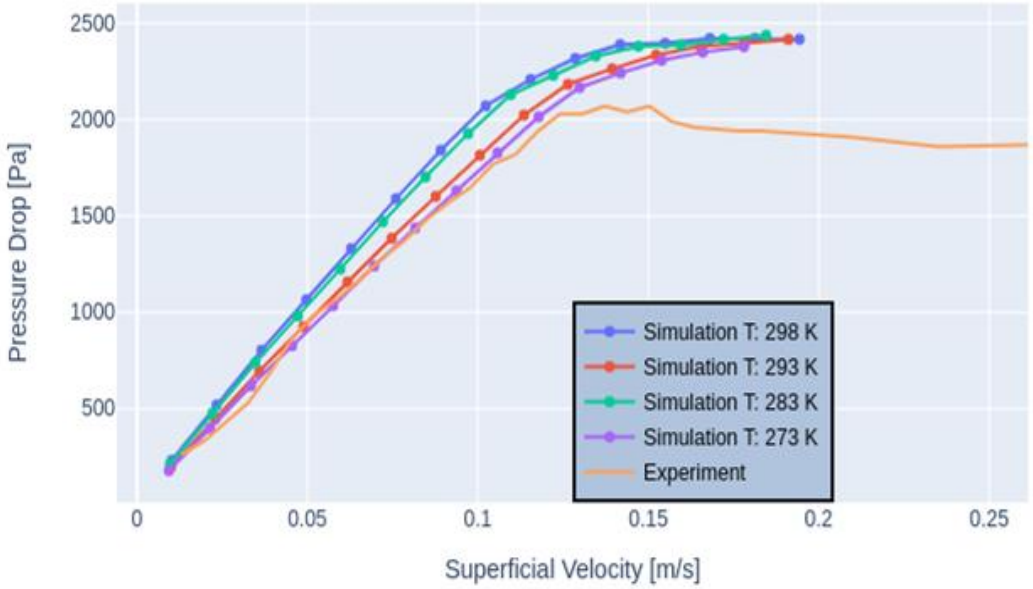


- Original Birmingham algorithm:
  - Up to 4 particles
- Line-density method:
  - Up to 8 particles
- PEPT-ML:
  - 128 ***at least***

Nicuşan, A. L., and C. R. K. Windows-Yule. "Positron emission particle tracking using machine learning." *Review of Scientific Instruments* 91.1 (2020): 013329.

Combining with Evolutionary Algorithms to provide powerful calibration/validation tool

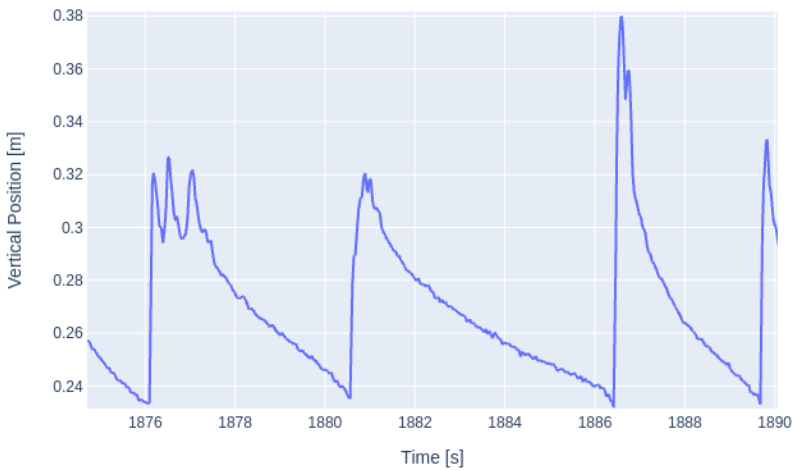
- Numerical models (CFD, DEM, CFD-DEM) are a powerful tool, but with an Achilles heel
- Many practitioners **do not rigorously calibrate or validate their simulations**



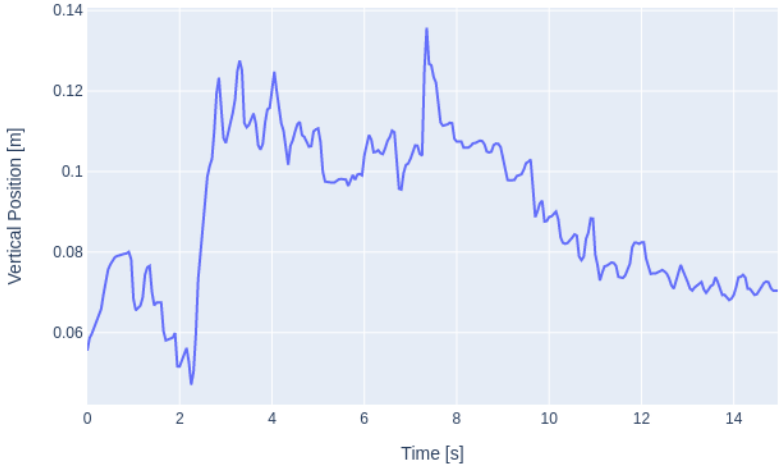
Reasonable calibration?

Combining with Evolutionary Algorithms to provide powerful calibration/validation tool

PEPT

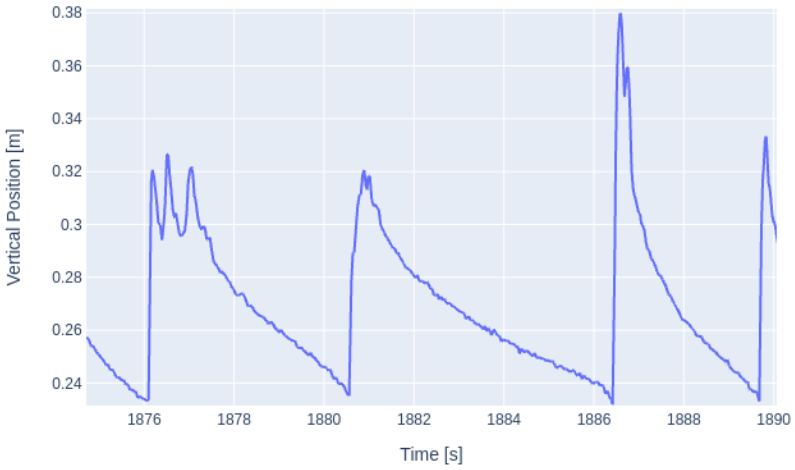


MP-PIC



Combining with Evolutionary Algorithms to provide powerful calibration/validation tool

PEPT



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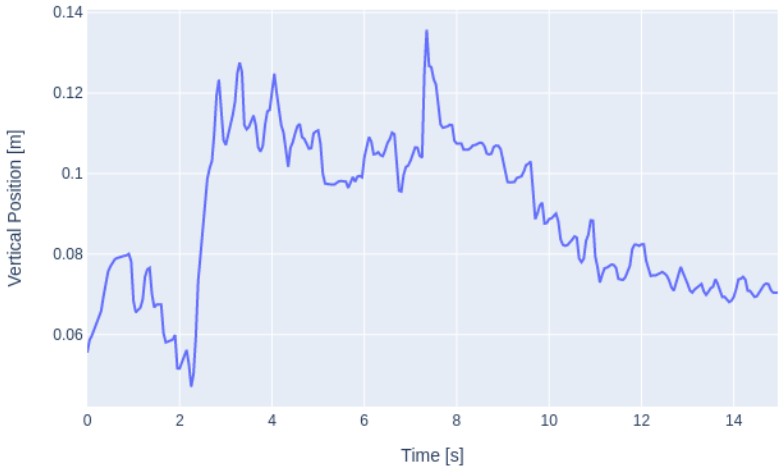
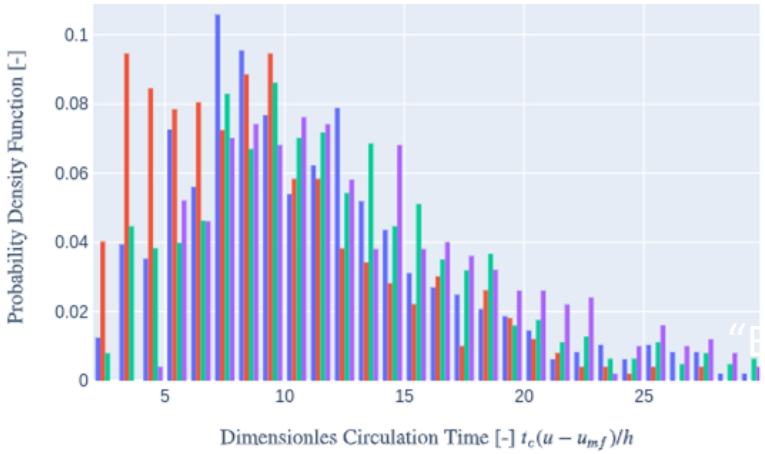
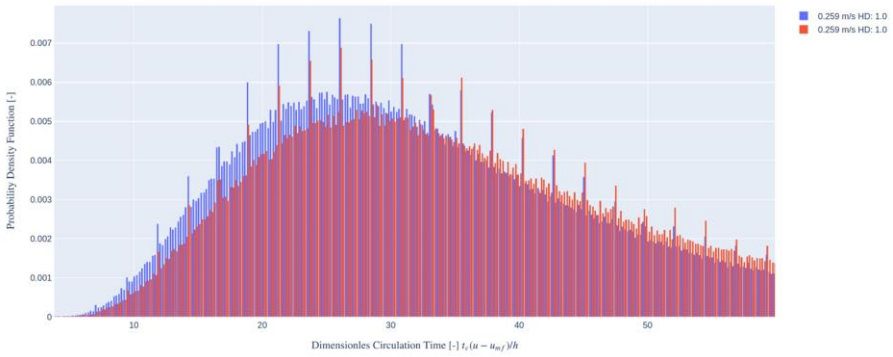
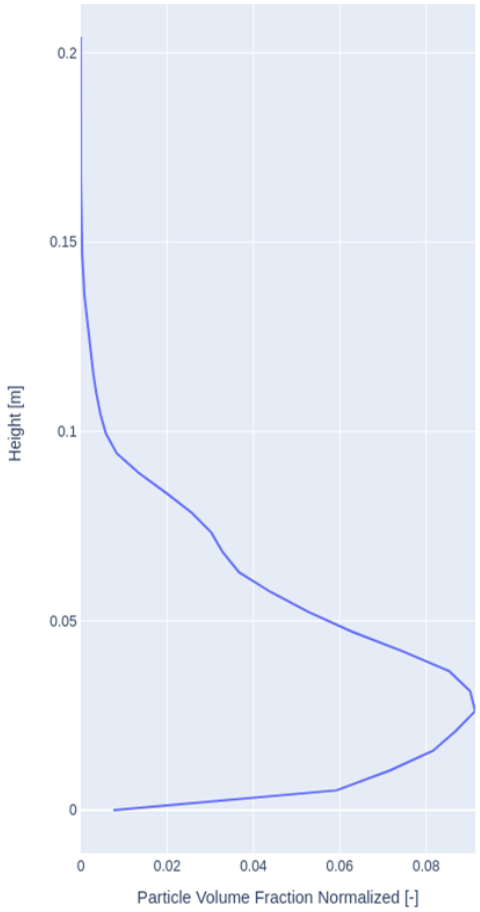






Combining with Evolutionary Algorithms to provide powerful calibration/validation tool

PEPT



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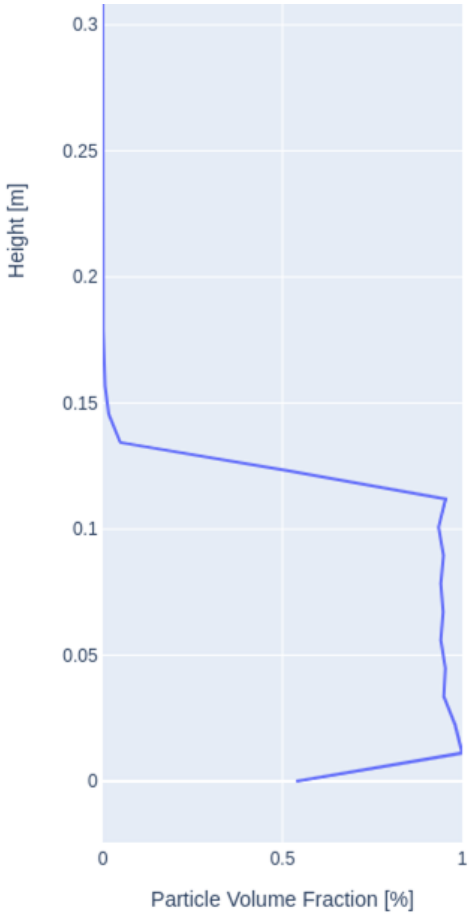
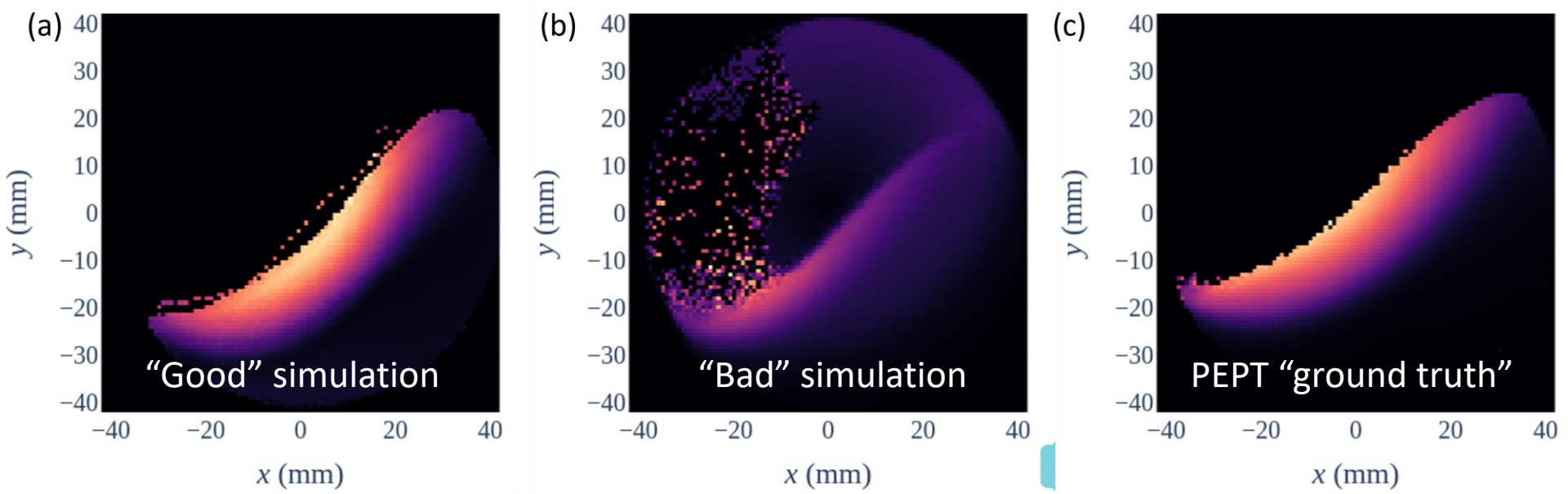


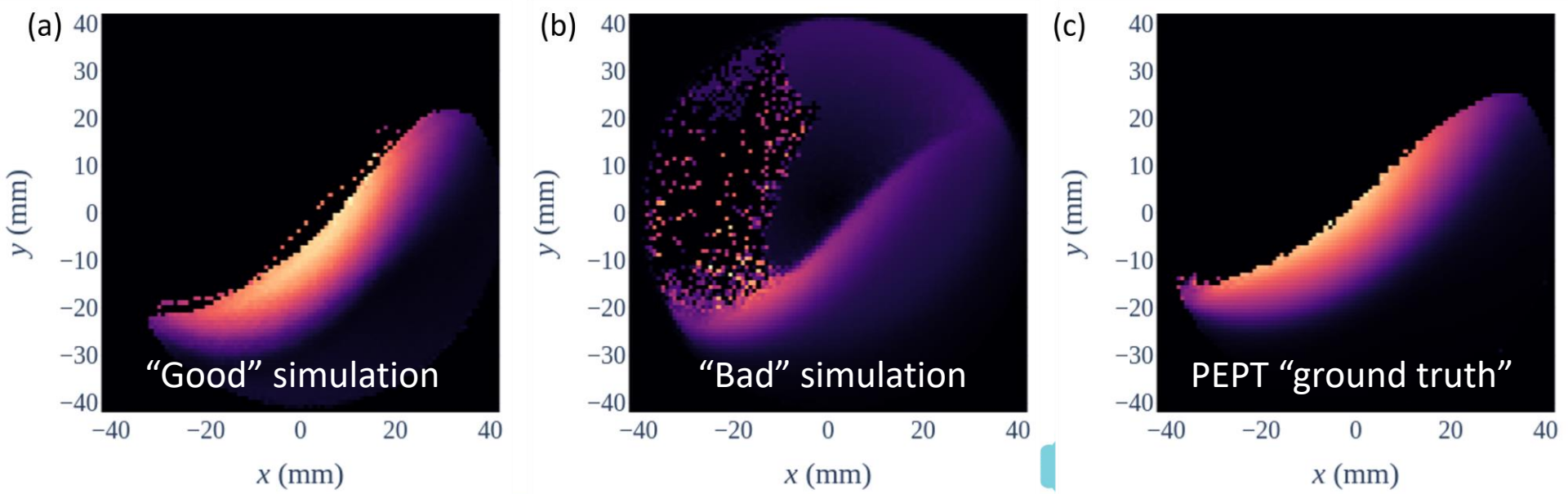
Combining with Evolutionary Algorithms to provide powerful calibration/validation tool

- PEPT provides highly-resolution three-dimensional data regarding myriad quantities
- → **Detailed, multi-point validation** (as required for complex systems!)



Combining with Evolutionary Algorithms to provide powerful calibration/validation tool

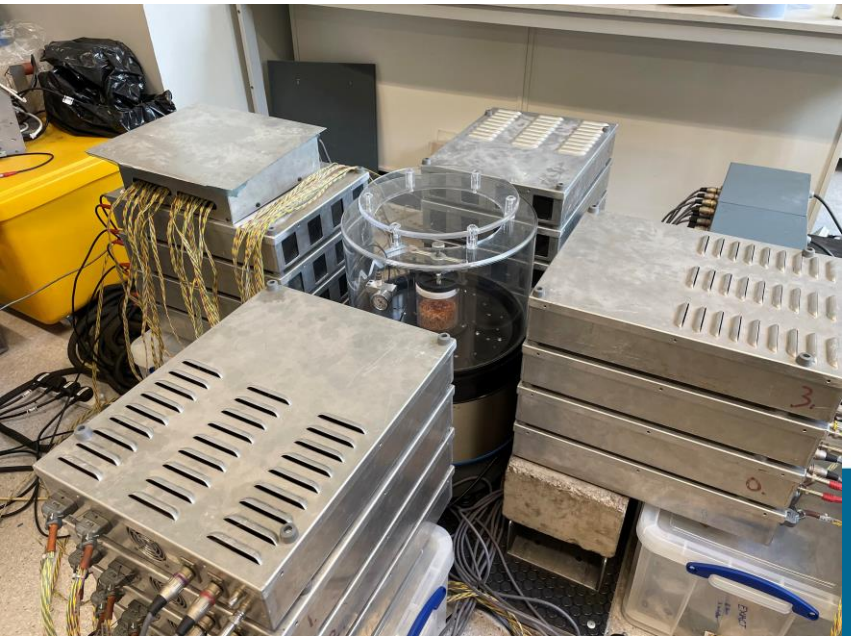
- Valuable for use with “ACCES” algorithm – see talk of Leonard Nicusan!



If the mountain won't come to Muhammad…

Engineering and Physical Sciences Research Council

?



- Modular camera
  - Arbitrary geometries
  - Large systems
  - *In situ* imaging

THE ROYAL SOCIETY

Royal Academy of Engineering

The Team

Zoe Chu

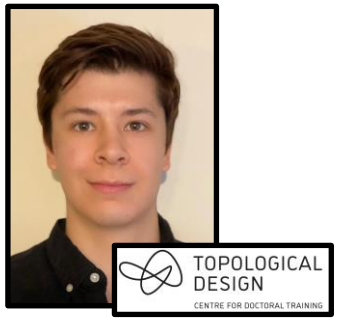
Matthew Herald

Owen Jones-Salkey

Issa Munnu

Leonard Nicuşan

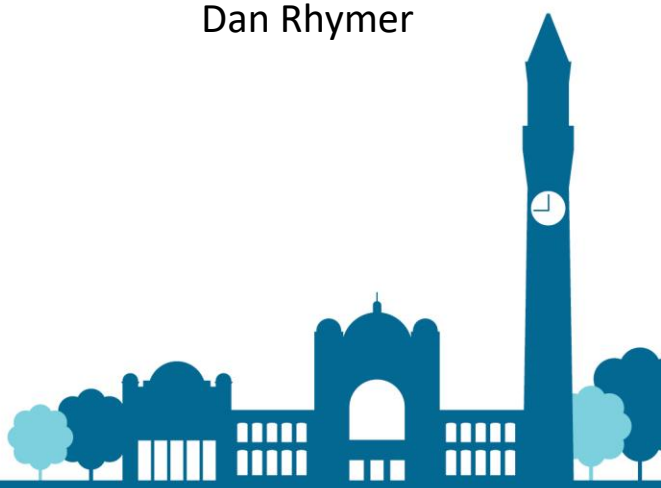
Dan Rhymer



Jack Sykes

Dominik Werner

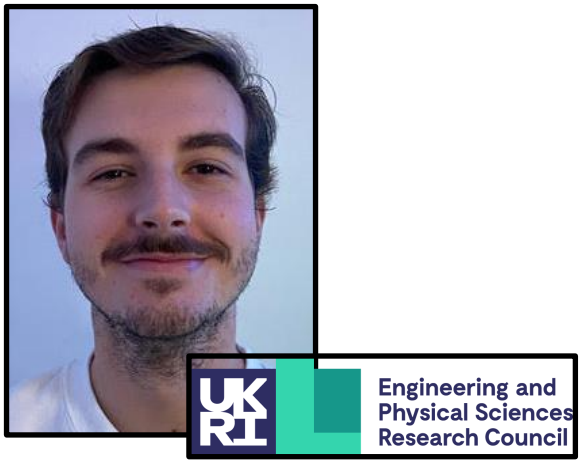
Dan Weston



The Team

Dominik Werner

Leonard Nicuşan



Matthew Herald

Funder Acknowledgements

Royal Academy of Engineering

Grant Nos. IF\192015 & IF\2021_89

THE ROYAL SOCIETY

Grant No. RGS\R1\201054

UKRI Engineering and Physical Sciences Research Council

Grant No. EP/T034327/1

UKRI Innovate UK

Grant No. KTP 11903

MAPP Manufacture using Advanced Powder Processes EPSRC Future Manufacturing Hub

Grant No. 1239412

GCRF Global Challenges Research Fund

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Any questions?

Anything piqued your interest?

Any ideas for valuable PEPT studies?

We are always open to exciting new collaborations!