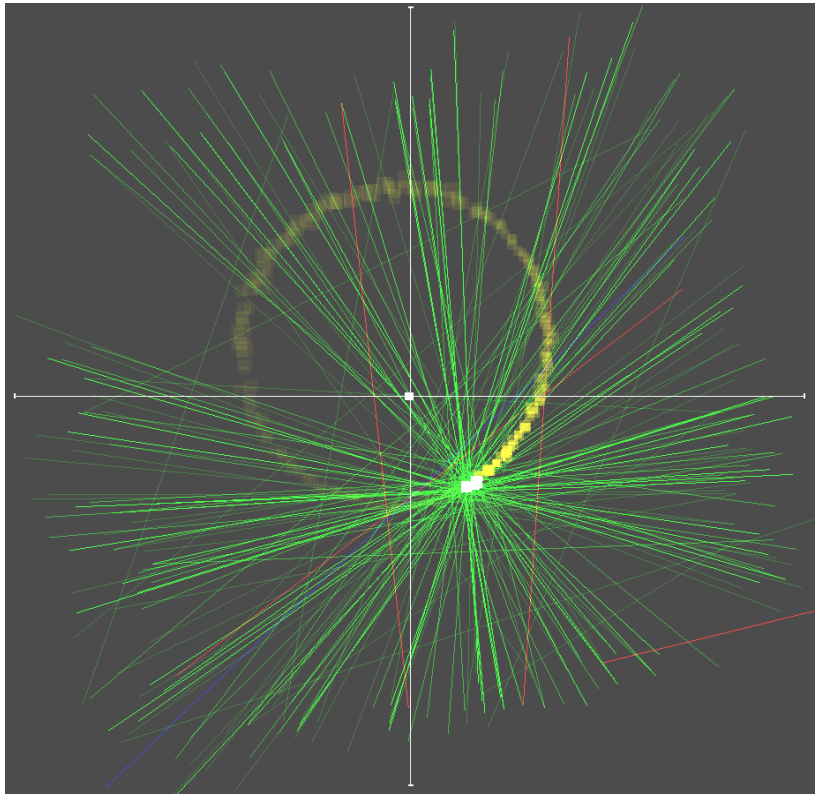
Positron emission particle tracking: a powerful nuclear application for flow studies



Andy Buffler, Tom Leadbeater
Katie Cole, Mike van Heerden

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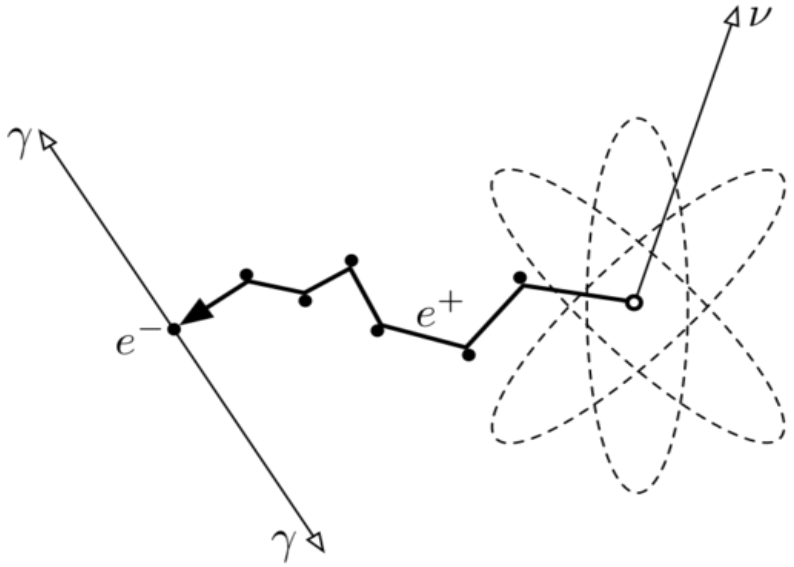
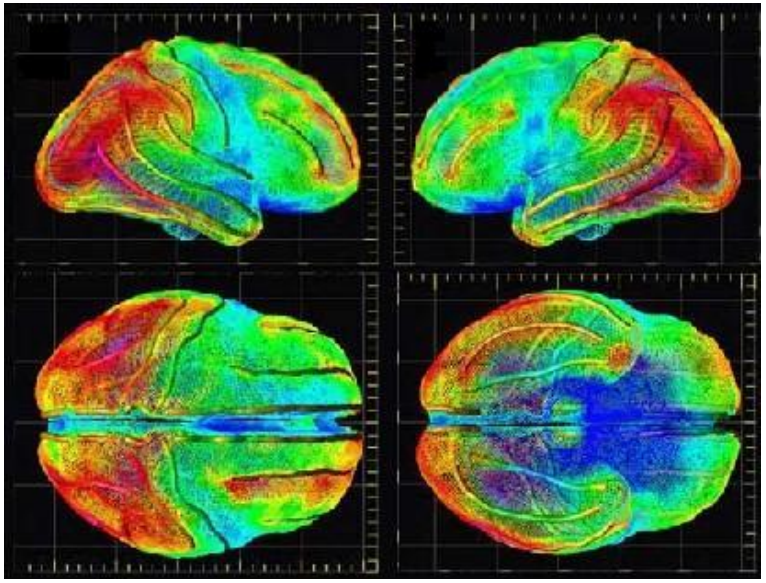
Medical imaging based on positron emission tomography (PET) continues to have wide-ranging clinical impact, particularly in cancer diagnosis and management, cardiology and neurology.





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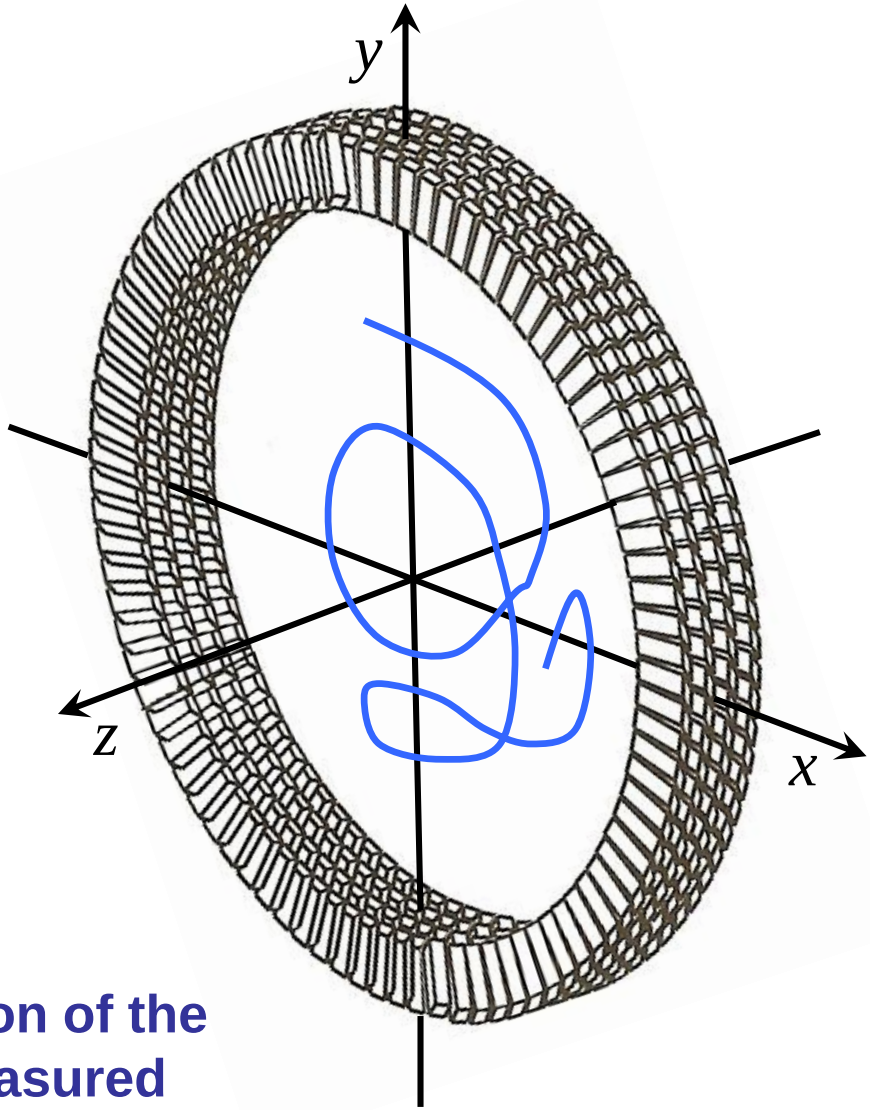
Positron Emission Particle Tracking (PEPT)

… PEPT is a technique which tracks the trajectory (*x*, *y*, *z*, *t*) of a tracer particle which has been labelled with a radionuclide that decays via positron emission. Developed in the 1990s at the University of Birmingham.

… tracer particles range in size from a few millimetres to below 0.1 mm and may be moving within a very aggressive environment … … tumbling mill, flotation cell, gaseous flow system, …



PEPT allows the visualization of the path line of the particle, measured within the field of view of a PET camera.

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Positron Emission Particle Tracking (PEPT)

… is a tool for in-situ characterisation and visualization of particulate flow within aggressive industrial environments, such as tumbling mills, powder mixers and flotation cells.

… PEPT results useful for the development of physics-based models of particle flow, and for validation of computational models (DEM, CFD, SPH, …)

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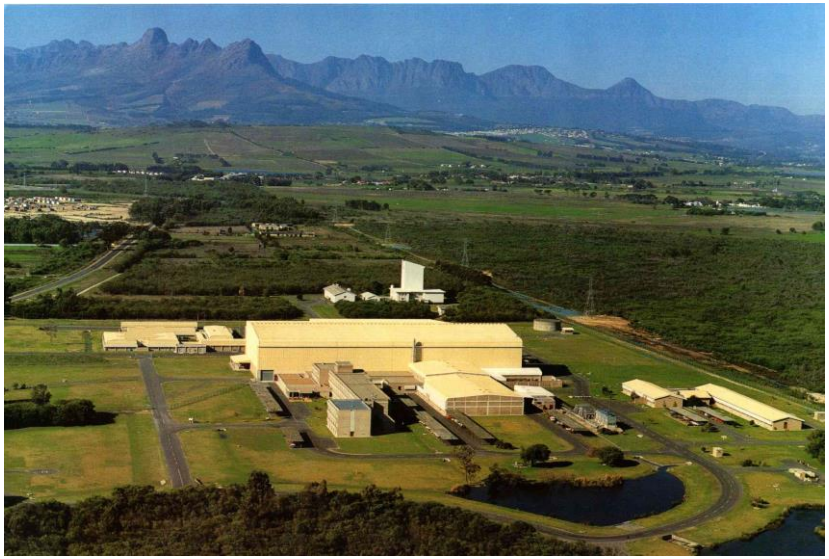

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NRF
National Research Foundation

iThemba LABS
Laboratory for Accelerator Based Sciences

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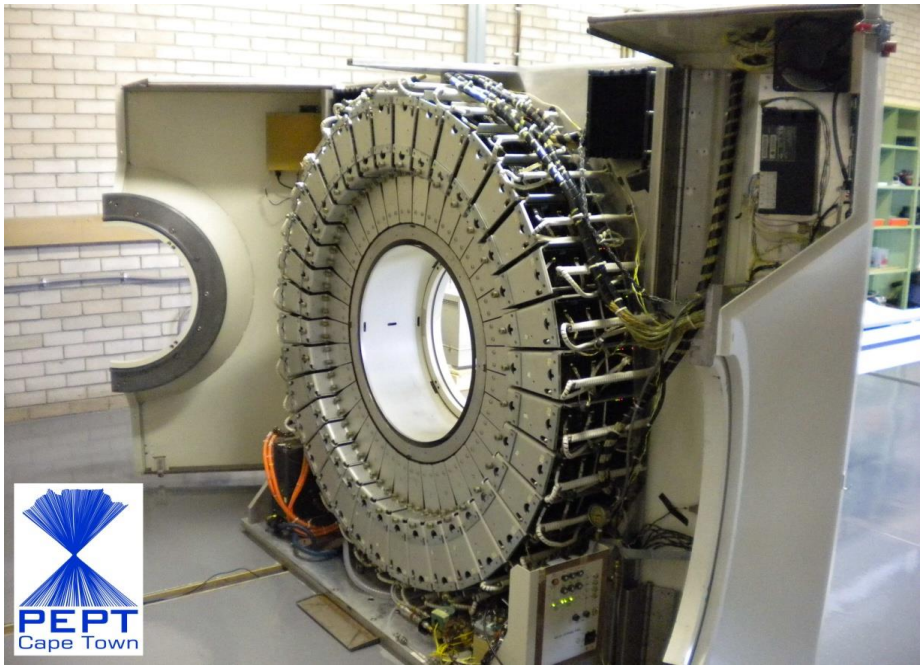
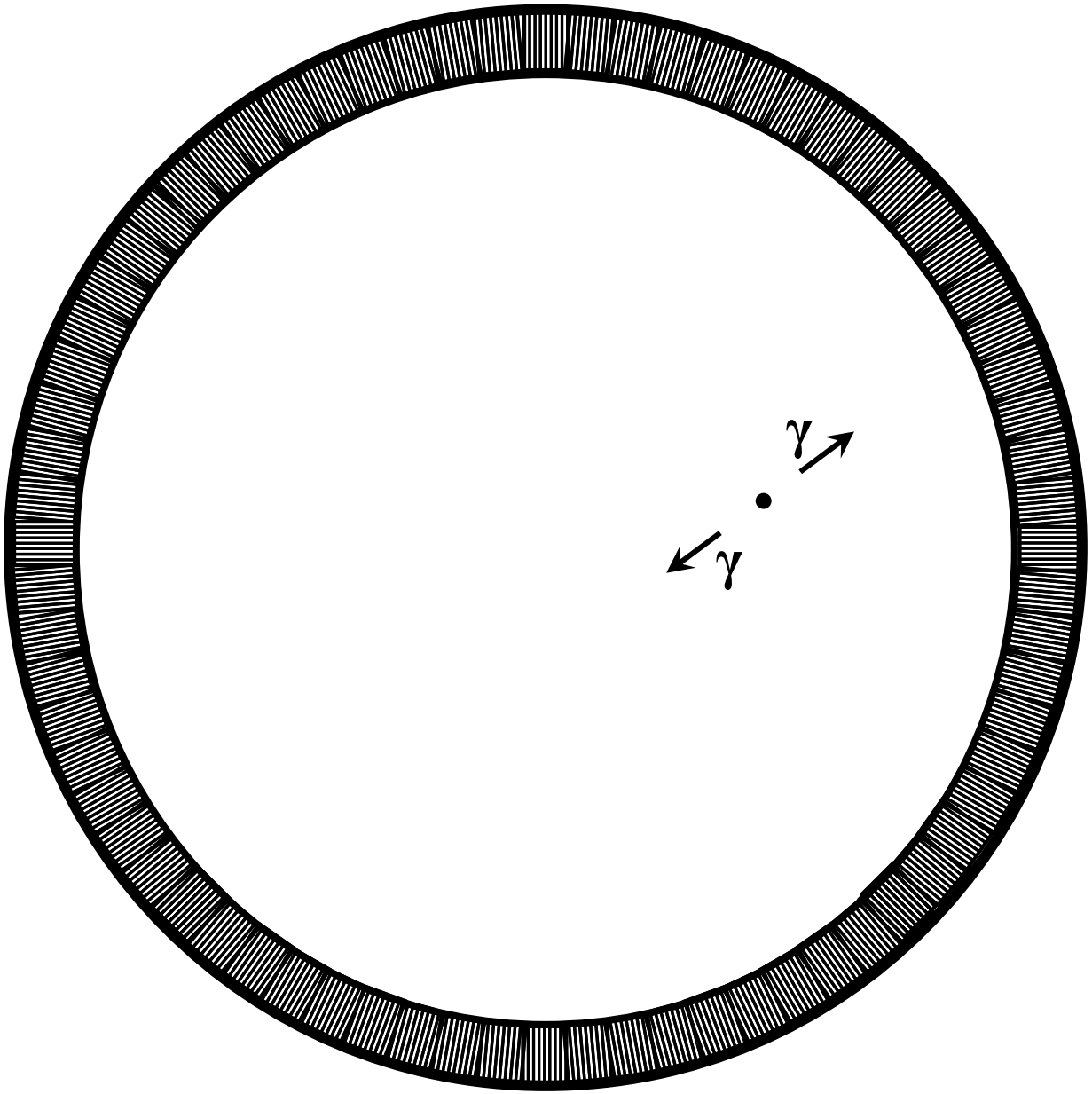


The “EXACT3D” Siemens HR++ PET scanner has over discrete 27000 detector elements.

The ADAC ”Vertex” gamma camera allows PEPT studies with a wider field of view …
… 500 x 600 x 800 mm^3.

Positron Emission Particle Tracking (PEPT)



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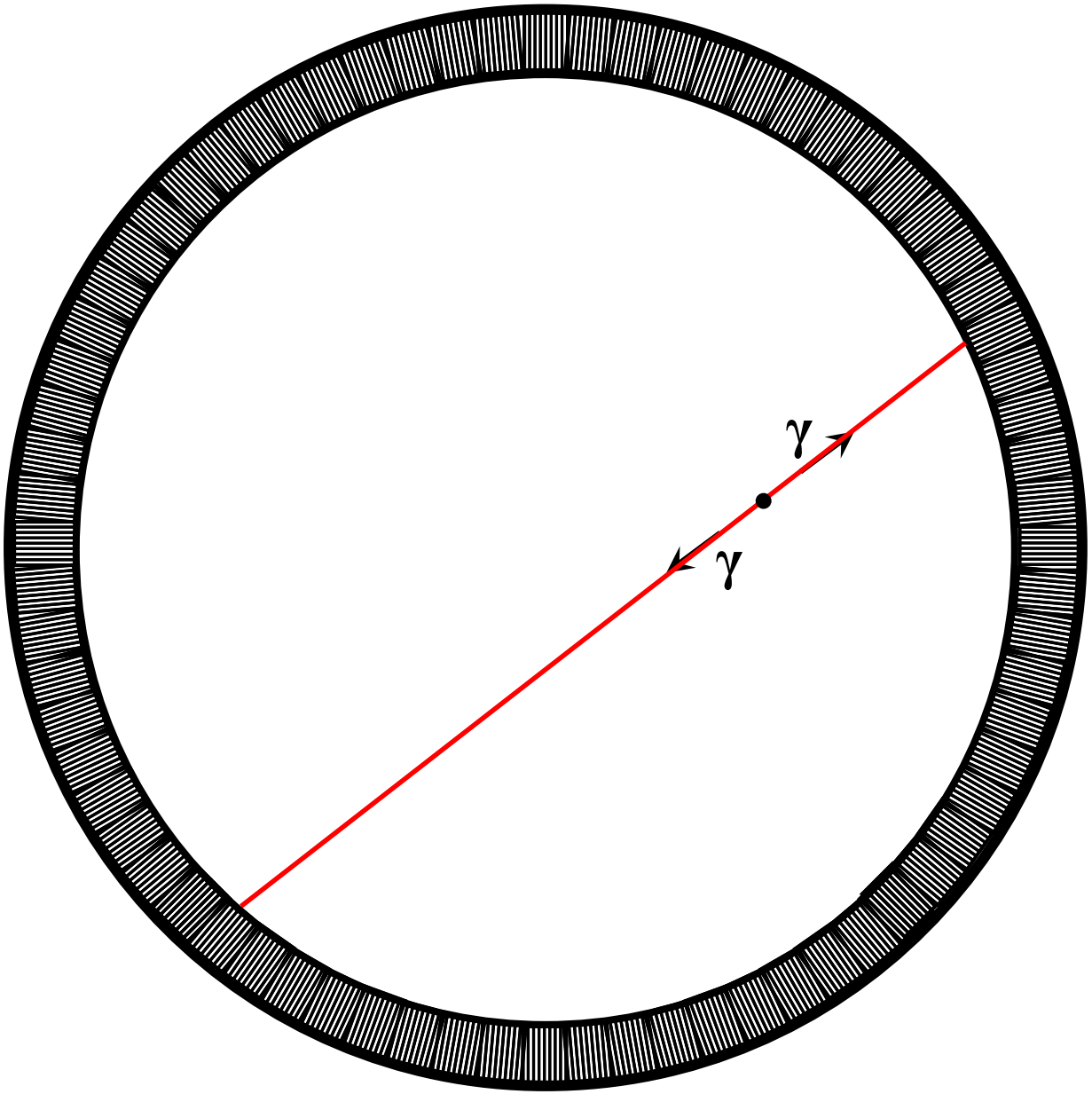
Positron Emission Particle Tracking (PEPT)



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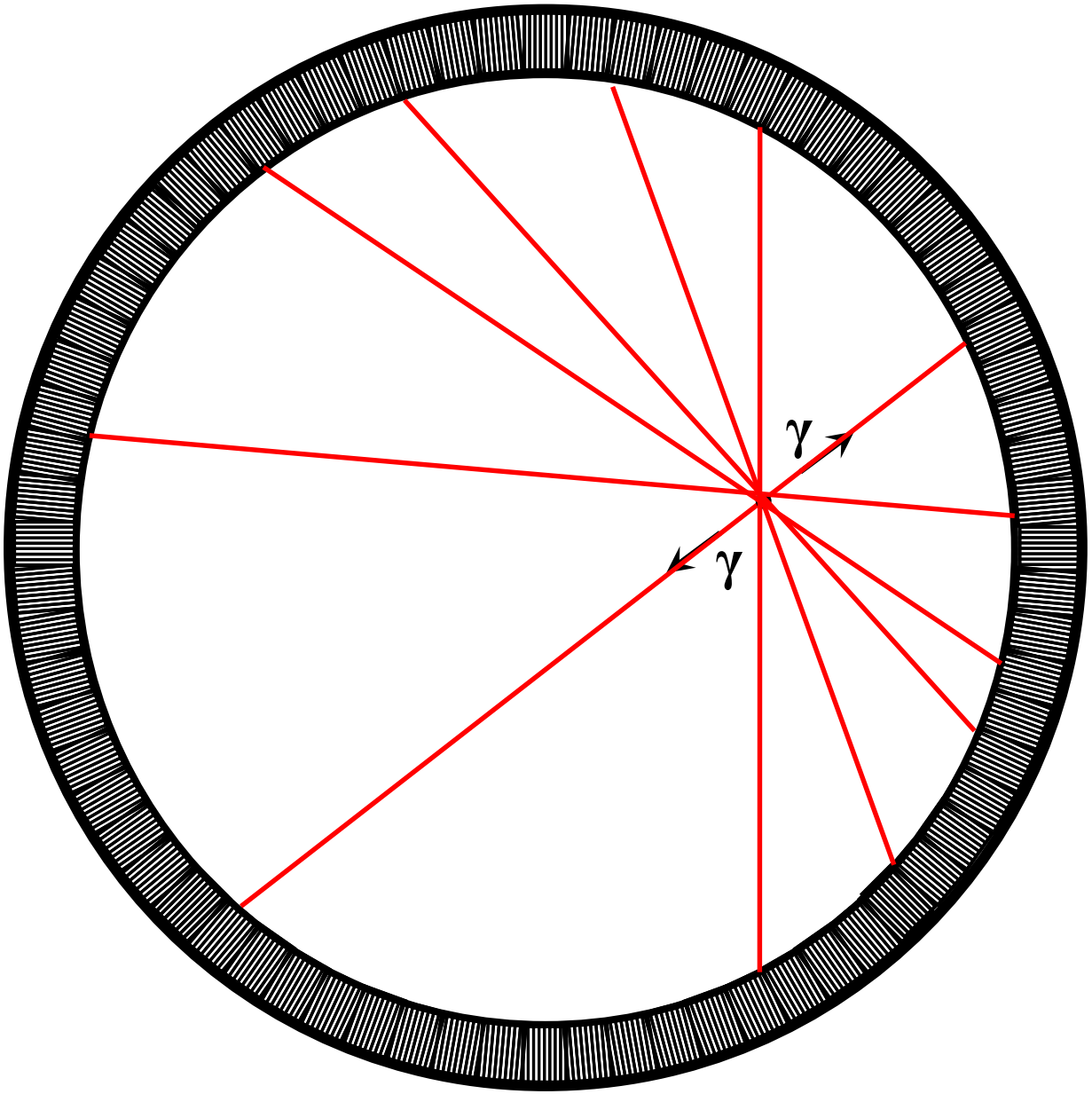
Positron Emission Particle Tracking (PEPT)



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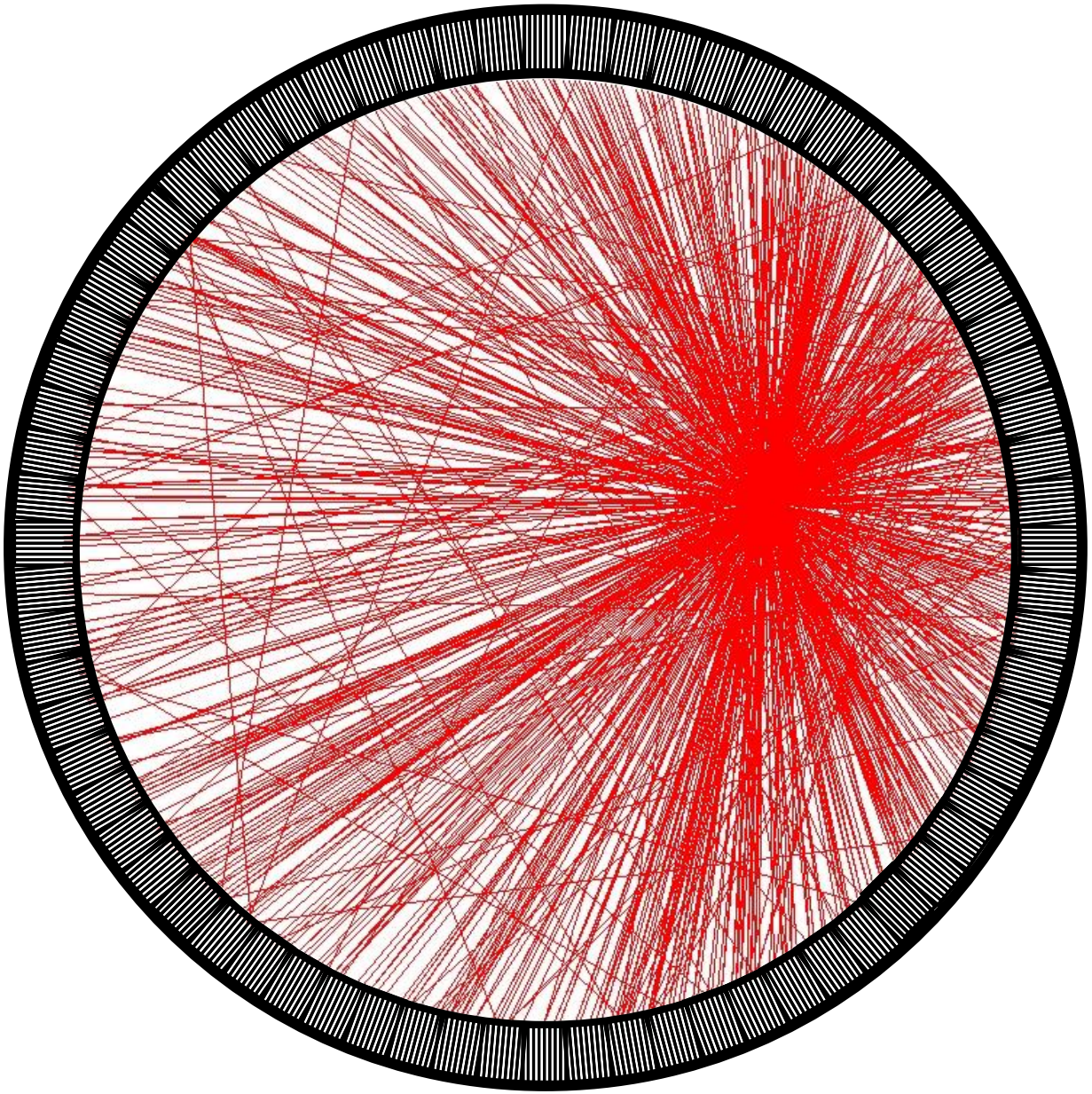

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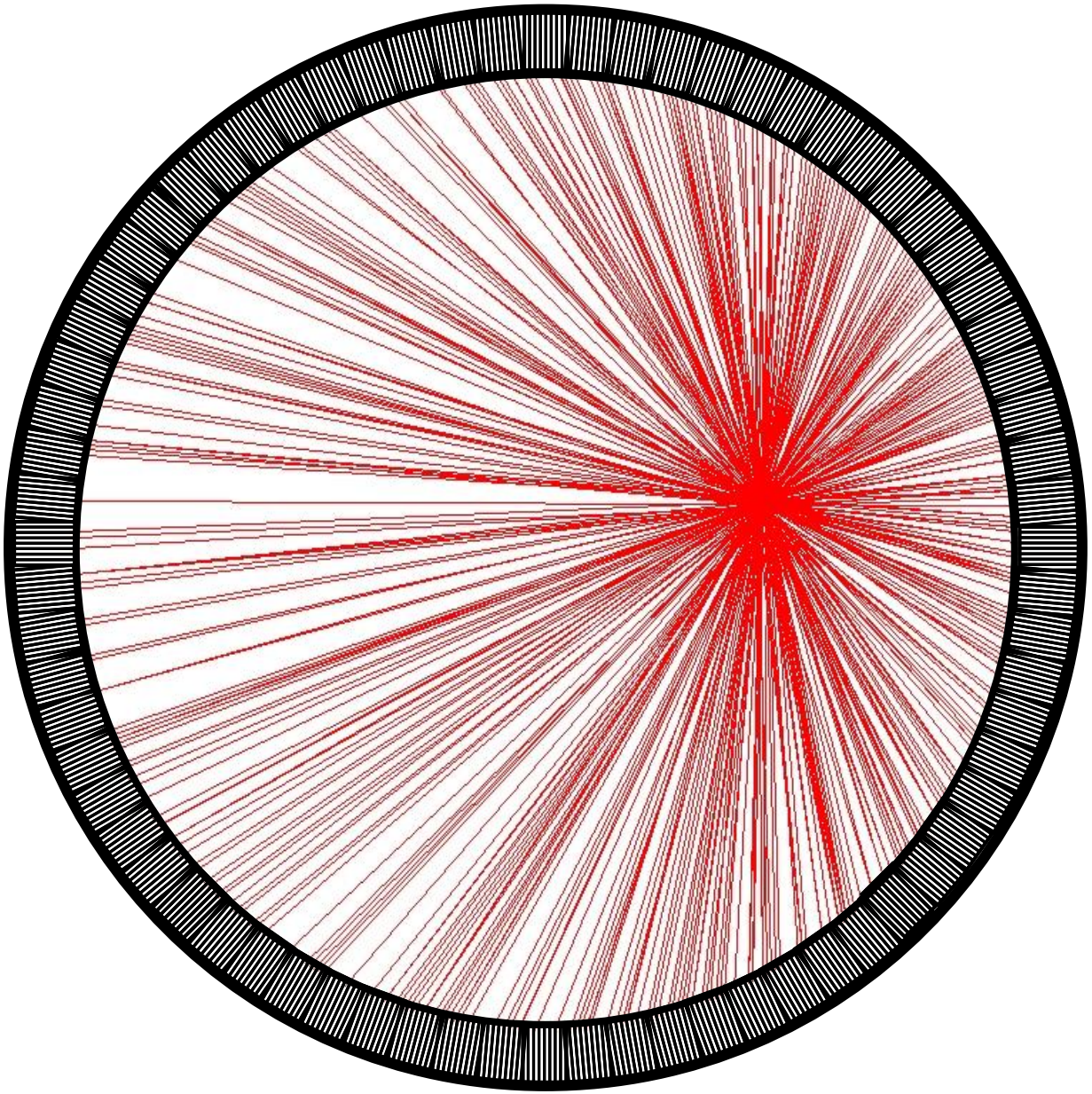

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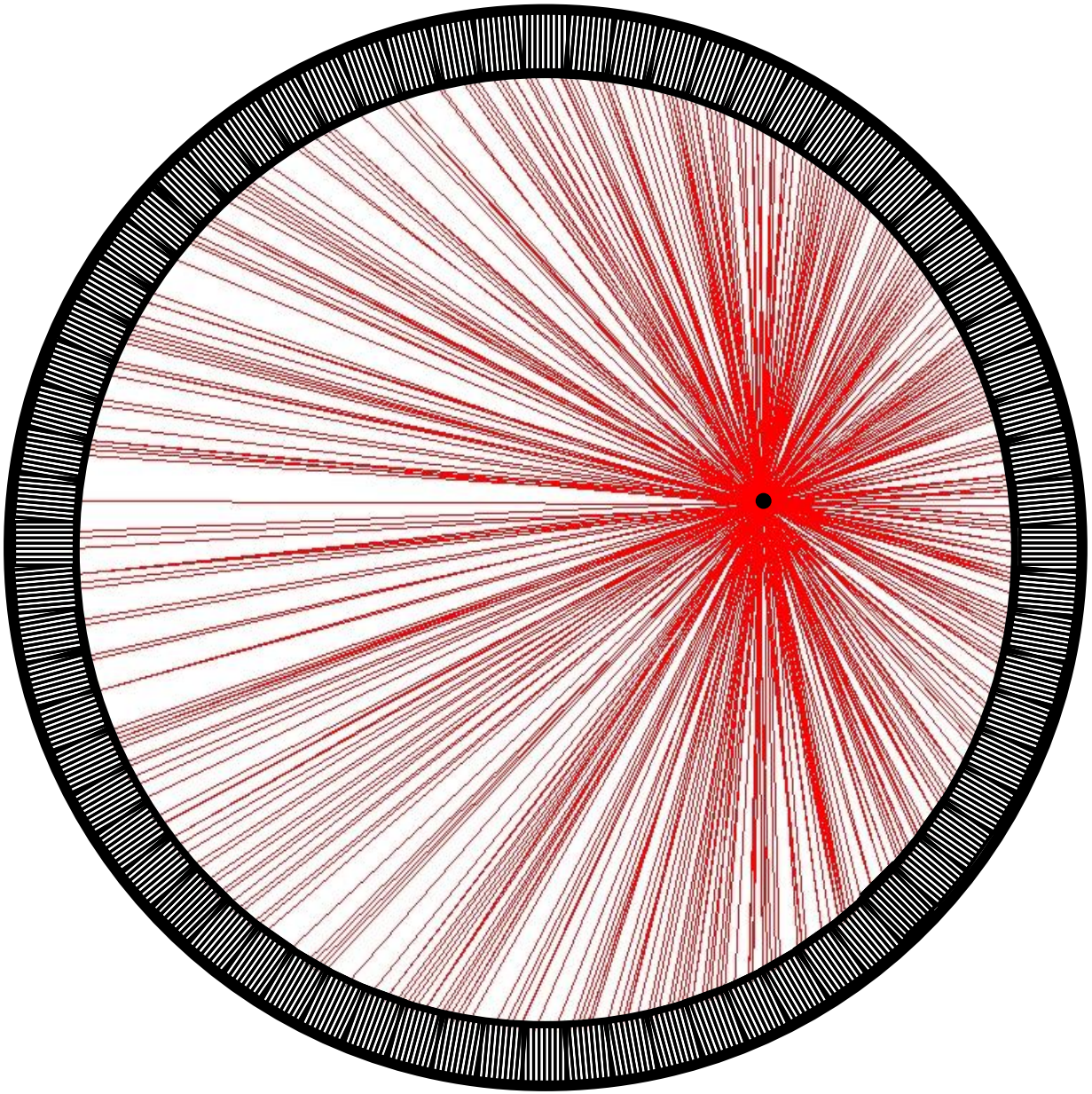

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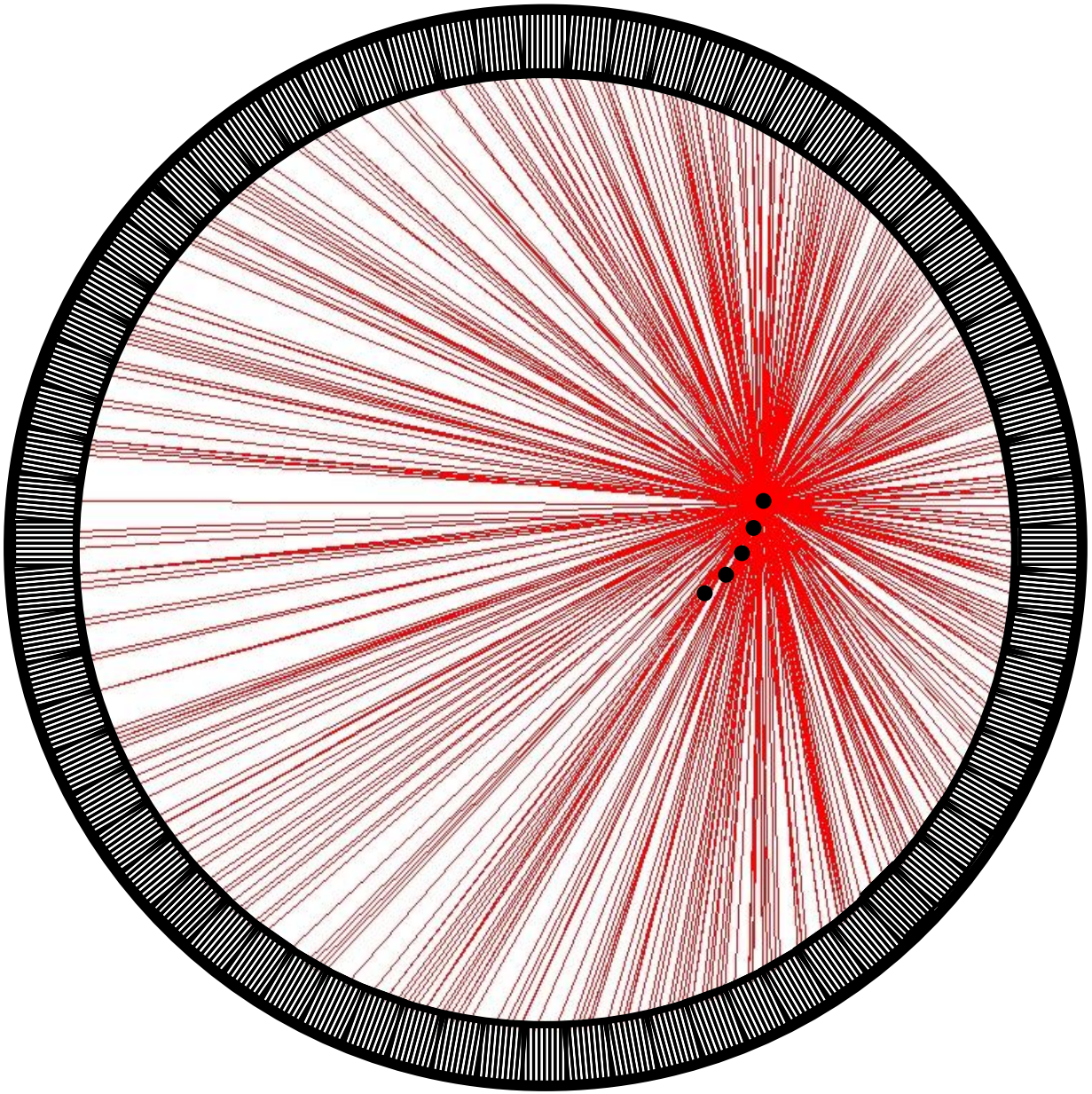

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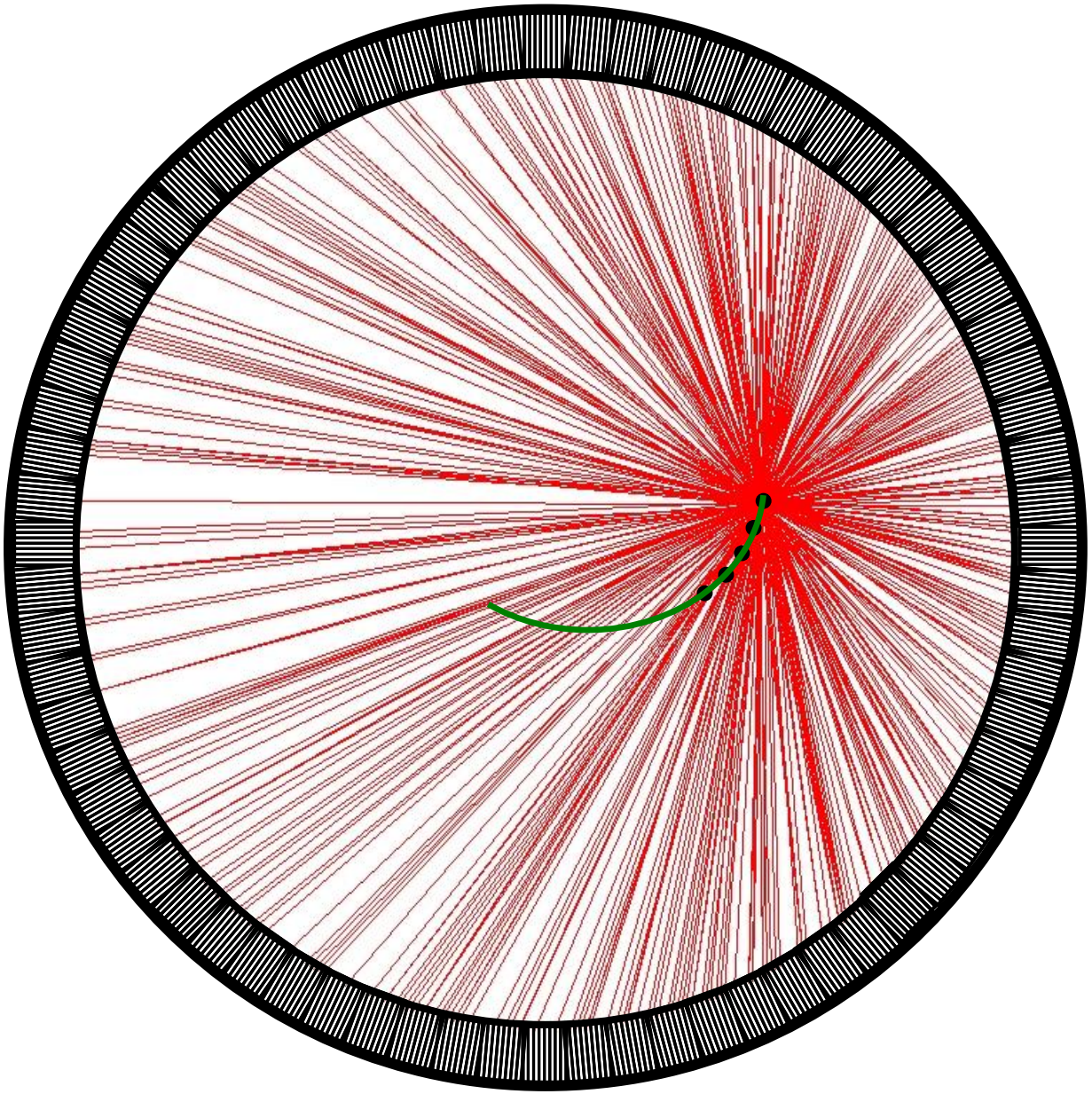

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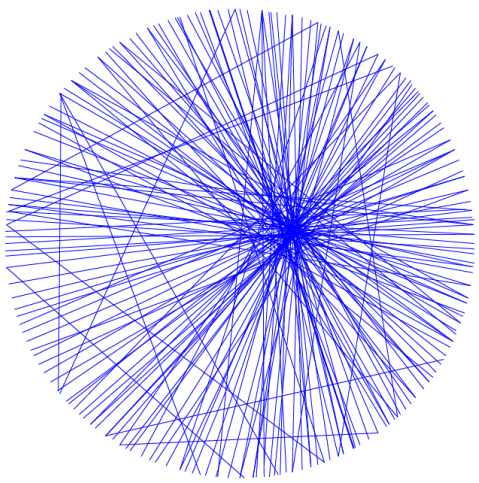
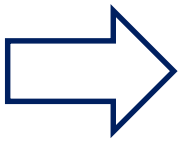
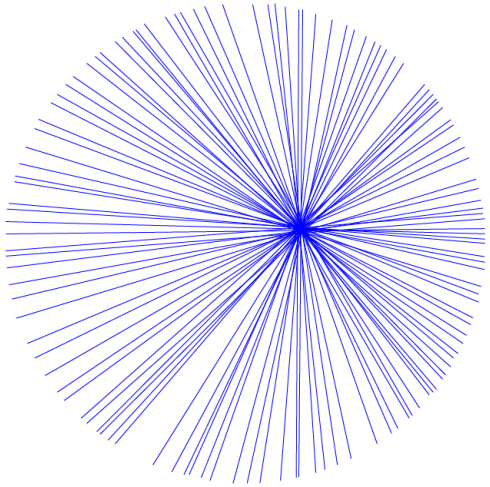
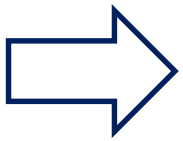
Triangulation of PEPT list mode data to produce (*x*,*y*,*z*;*t*)



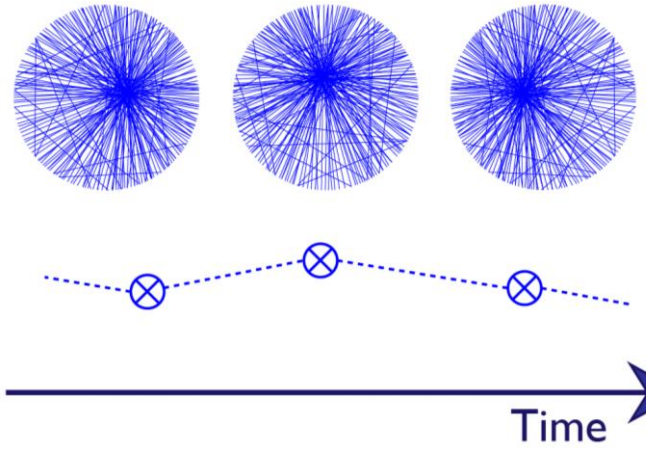


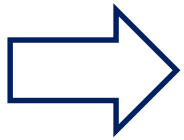


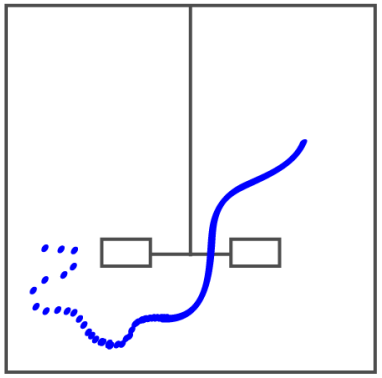


N – number of lines per slice

f – fraction of lines in each final location







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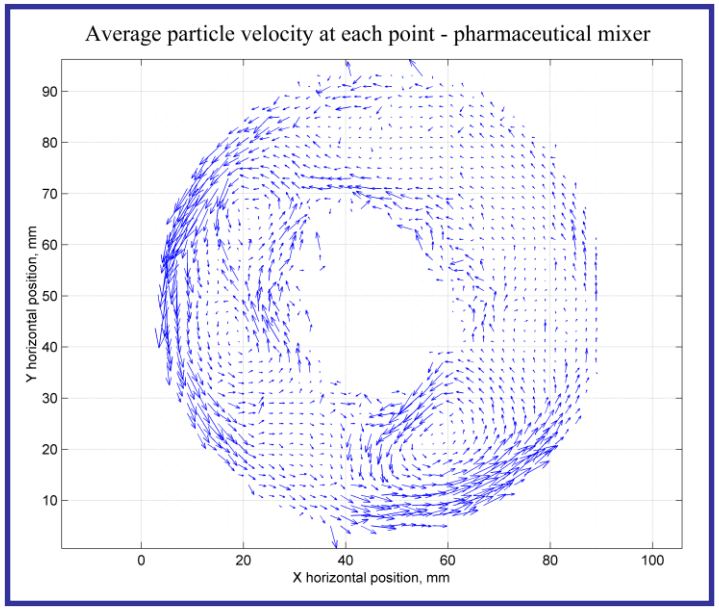
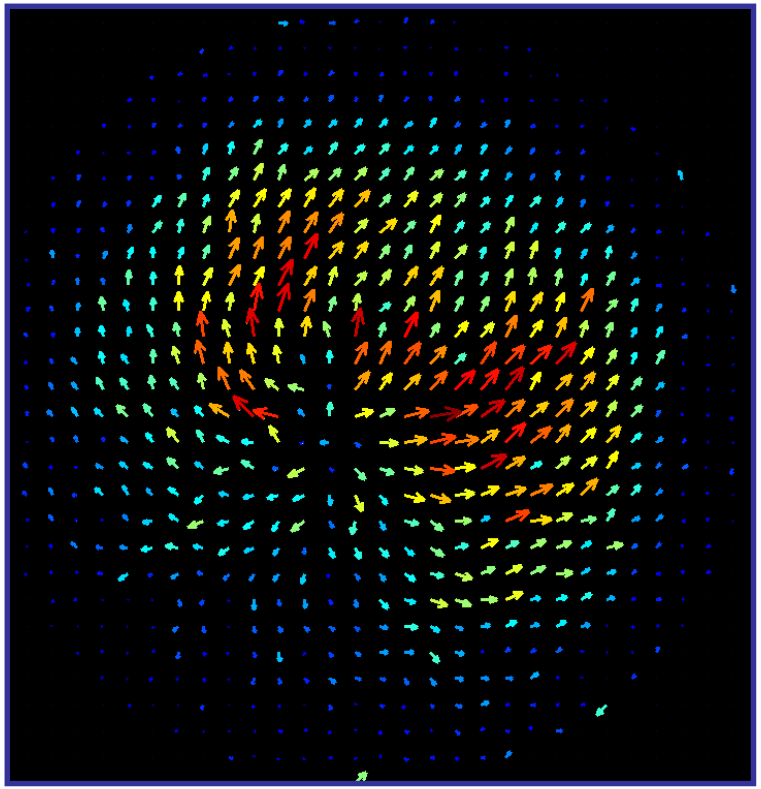
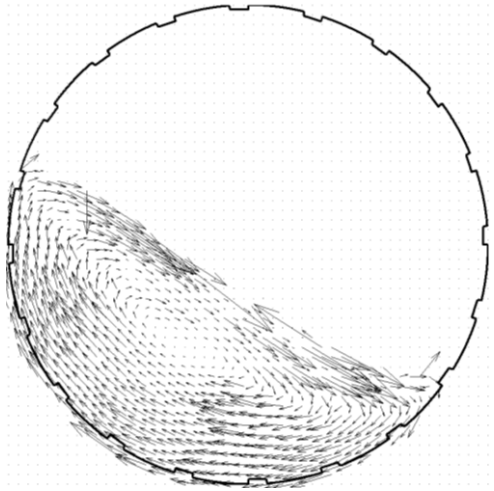
Velocities and accelerations are derived quantities







occupancy
vorticity
porosity
…

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Radioisotopes for PEPT

… critical feature of PEPT is that realistic tracers may be labelled …
… rock particles, tough resins, glass beads, …
… particle size range: 10 mm to 0.1 mm
… typical activities: 300 µCi to 1000 µCi

Techniques employed to label tracers involve:
… direct activation with a proton or ^{3}He beam,
… ion exchange nuclear chemistry
… modification to the surface of the tracer material.

PEPT isotope	Half life (minutes)
^{18}F	109
^{68}Ga	68
^{66}Ga	567
^{61}Cu	204
^{64}Cu	762
^{22}Na	(2.6 years)

Present research focus:
… labelling a sub-50 µm particle with > 300 µCi.

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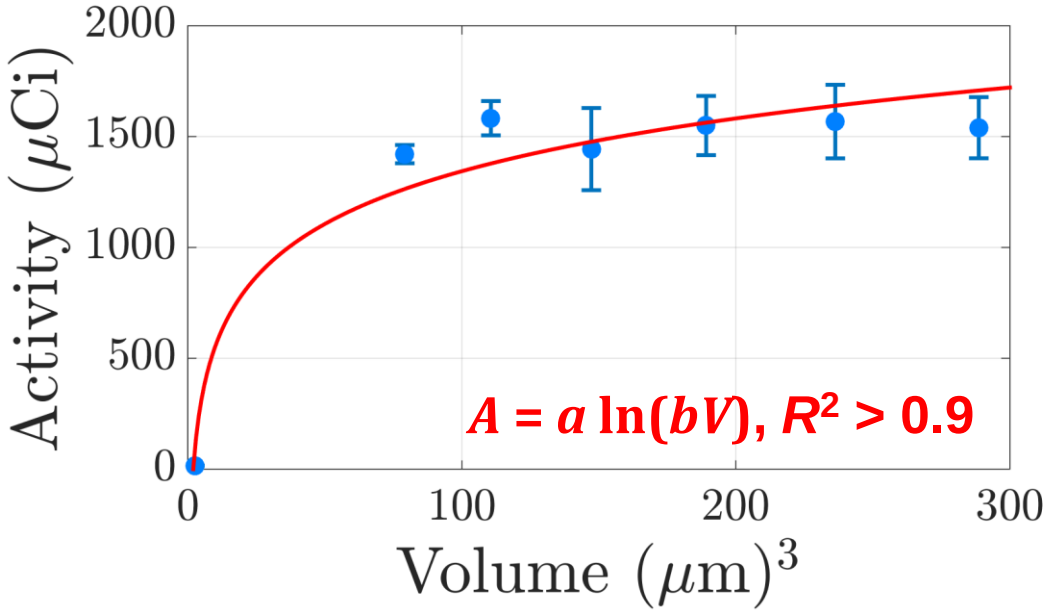
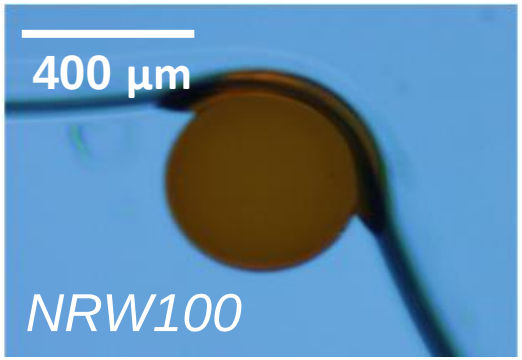
Tracer particles: ion exchange resins

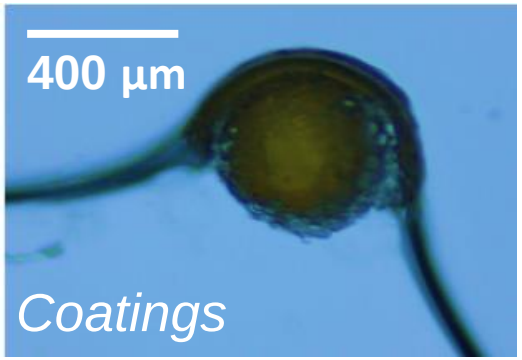
Radio-label with a short lived positron emitting radioisotope

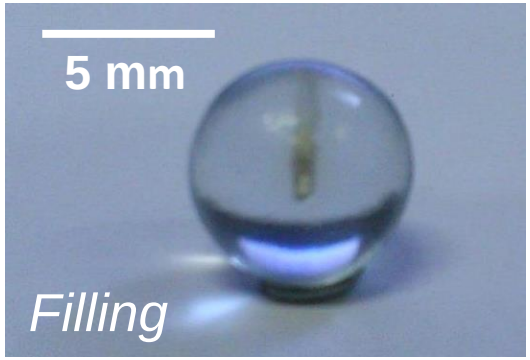
e.g. ^{18}F ($t_{½}$ = 109 min)
^{68}Ga ($t_{½}$ = 68 min)



Apply coating methods to reproduce properties of the system bulk







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A real world example: tumbling mill

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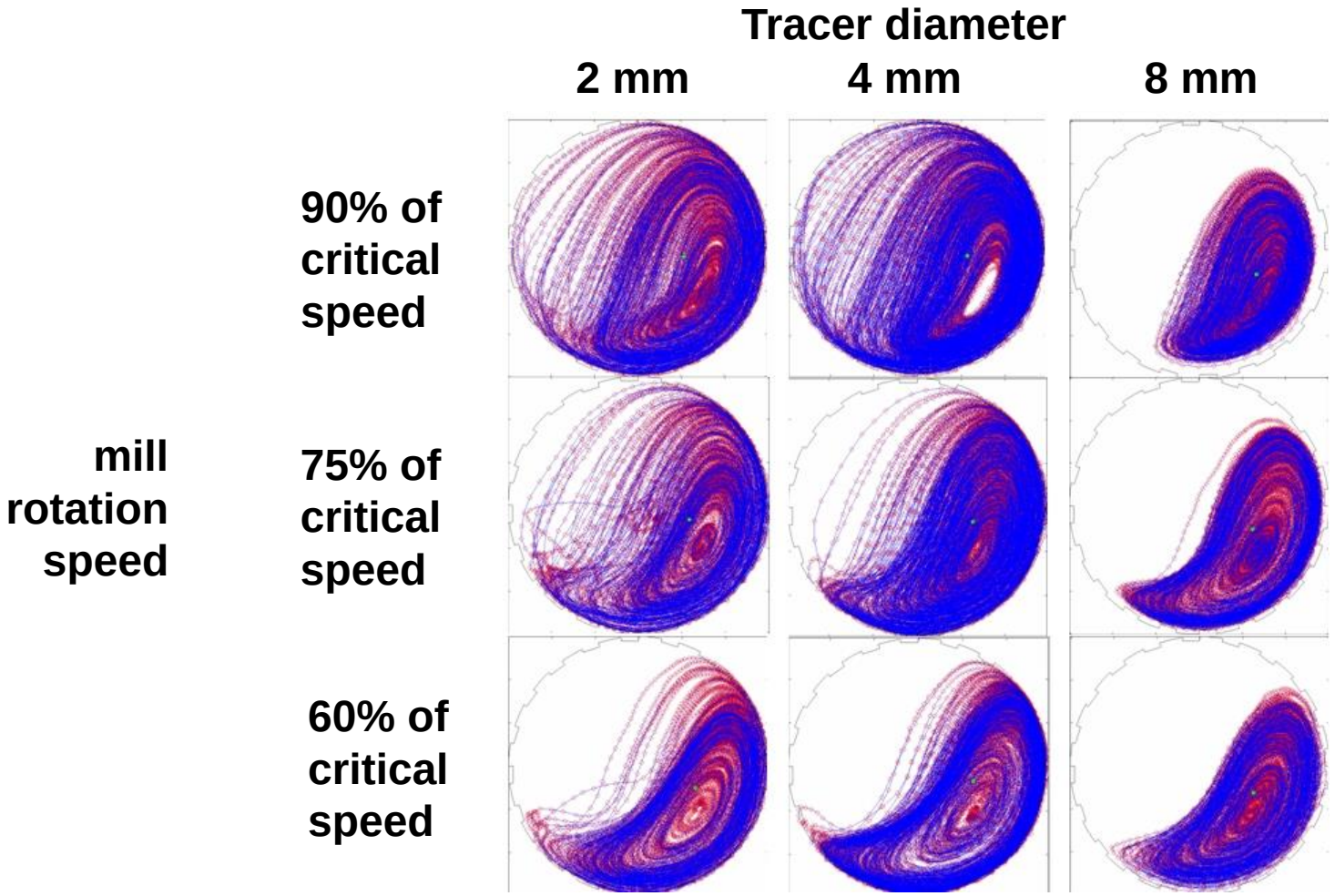

Trajectories measured via PEPT of labelled glass beads in a laboratory scale tumbling mill (projections onto the end face of the mill).

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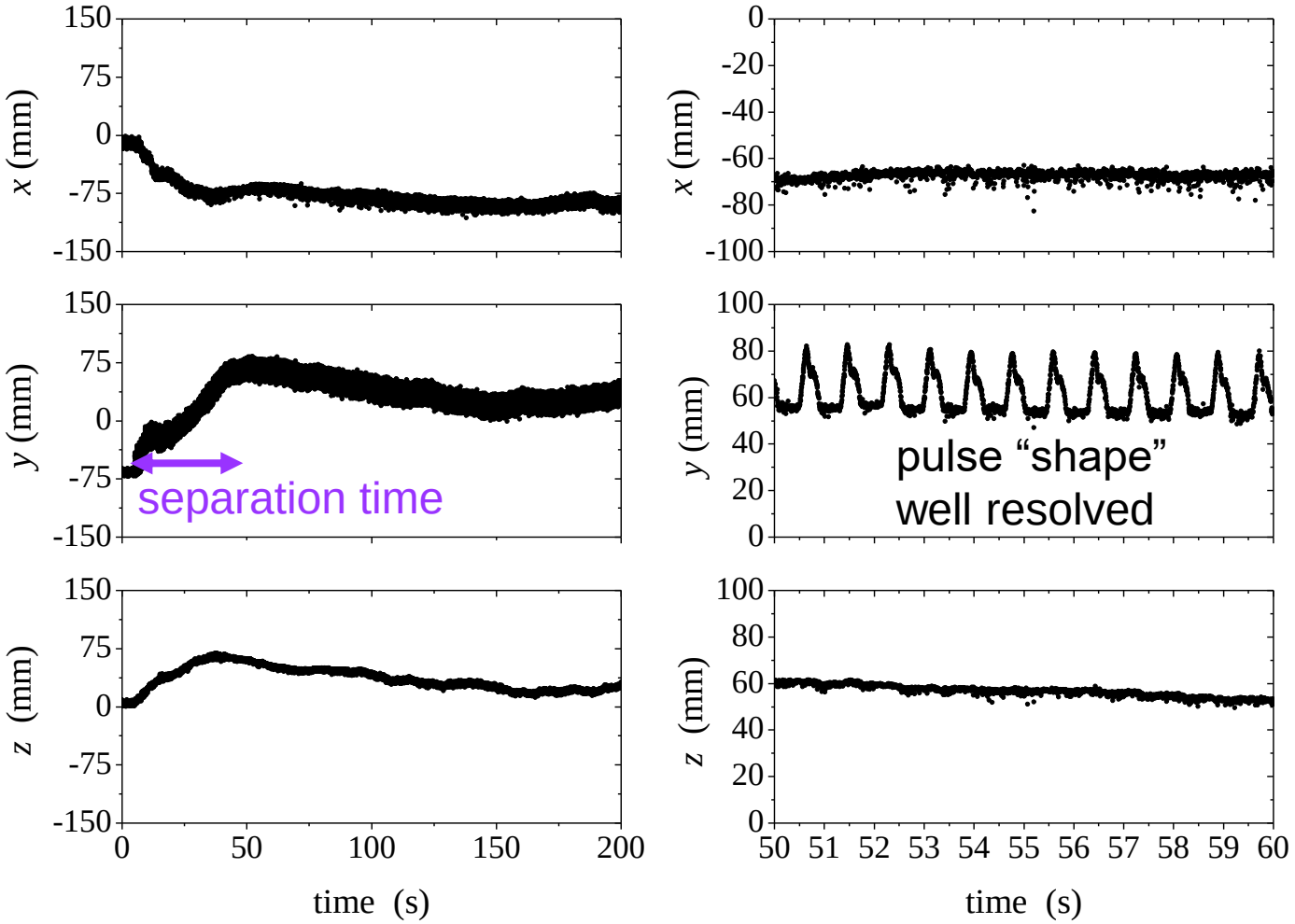
Jigging: measurements with a lab scale batch jig

One example … 5 mm ore tracer, mixed filling

vertical axis



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PEPT metrology

List mode data recorded in strict chronological order with a time stamp resolution on 1 ms.

A full uncertainty budget for PEPT is being developed, and is including inputs to the PEPT measurement equation from:

- **PET scanner detection system;**
- **activity of the tracer;**
- **species of radionuclide used;**
- **nature of the material between tracer and detector;**
- **speed of the tracer;**
- **triangulation algorithm.**

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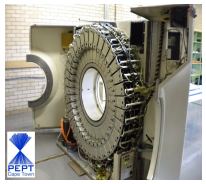
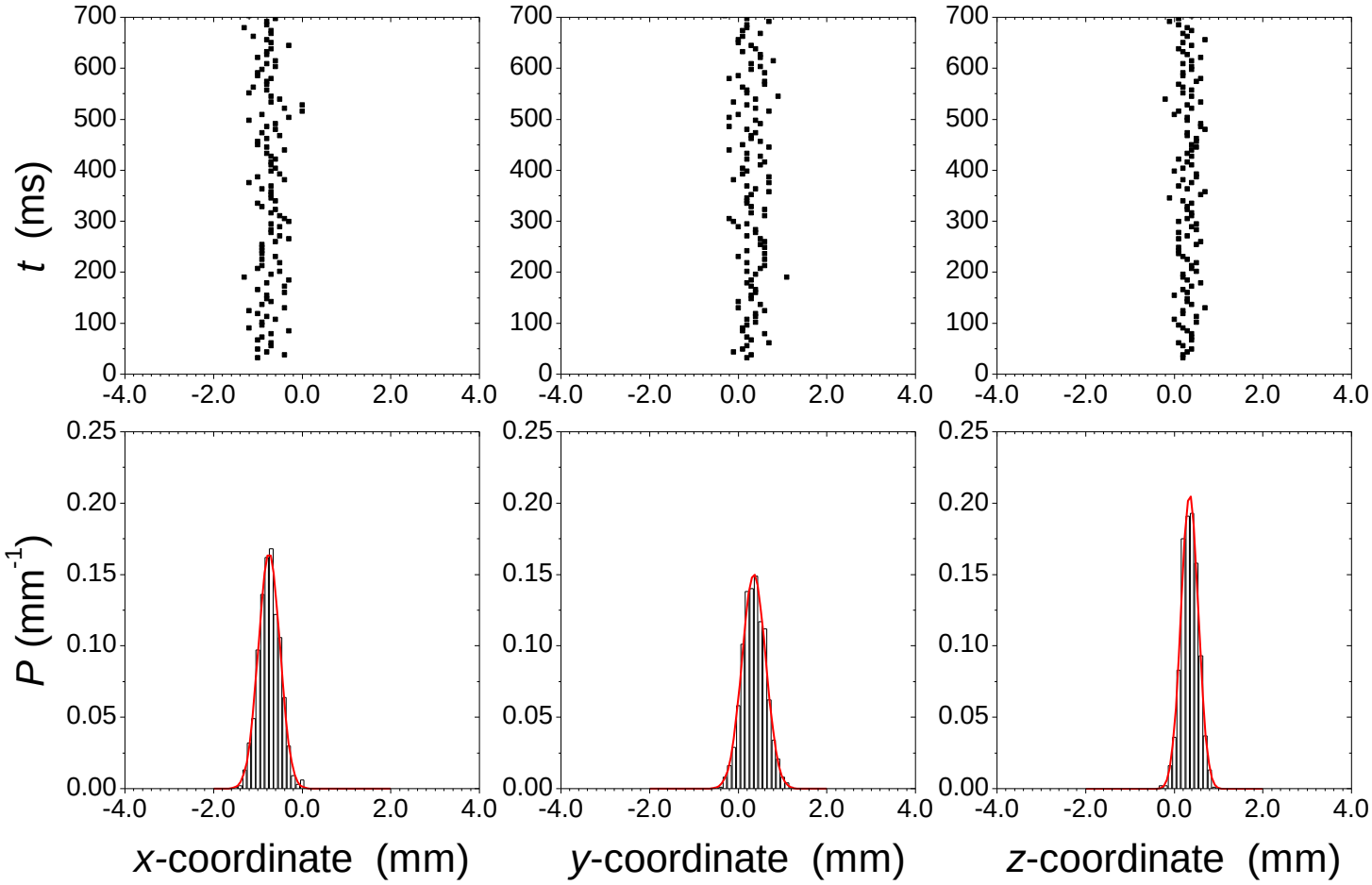


Stationary tracer: near centre of HR++ scanner

Labelled with 800 kBq of ^{68}Ga



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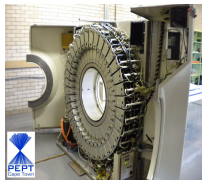
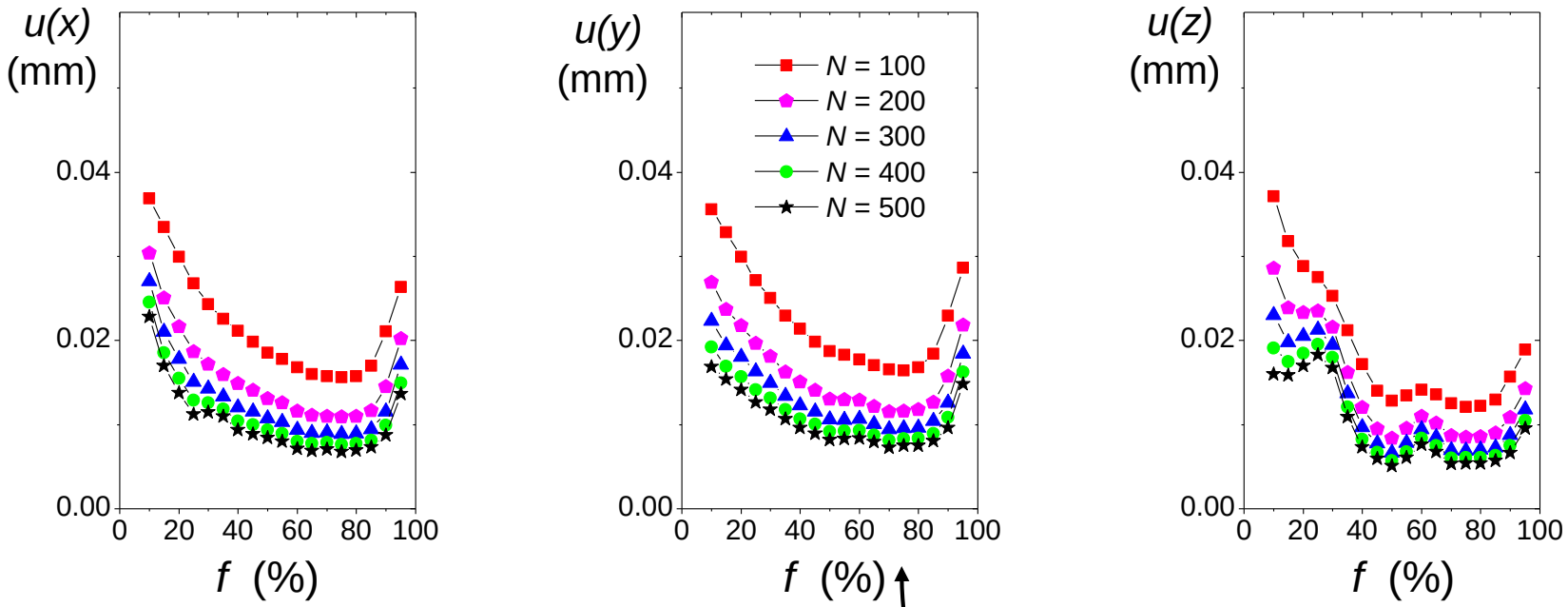


Stationary tracer: near centre of HR++ scanner

$$u(x) = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n}} \qquad u(y) = \sqrt{\frac{\sum (y_i - \bar{y})^2}{n}} \qquad u(z) = \sqrt{\frac{\sum (z_i - \bar{z})^2}{n}}$$



Minimum around *f* = 70%

… and select *N* = 400 to also maximise location rate

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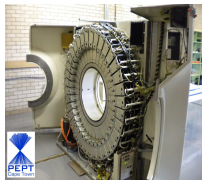
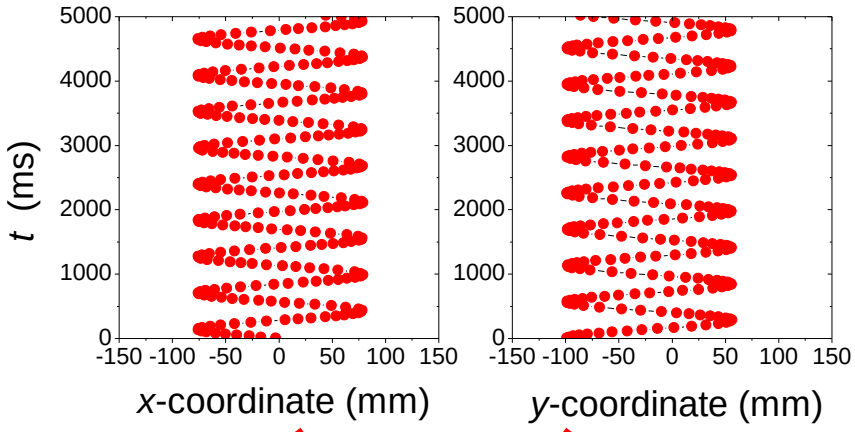
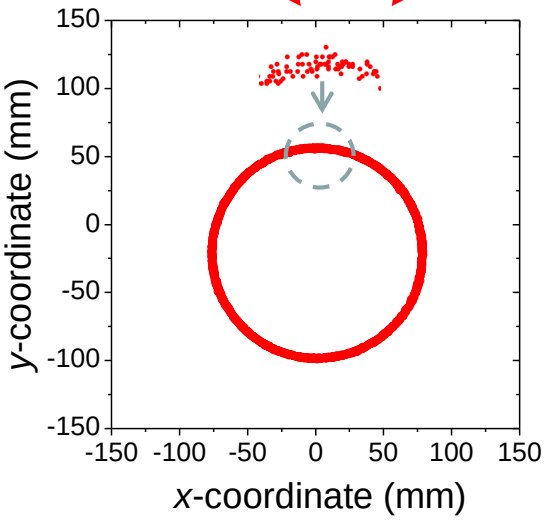
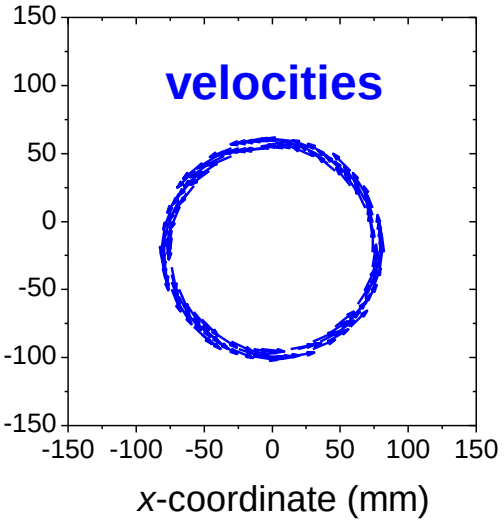


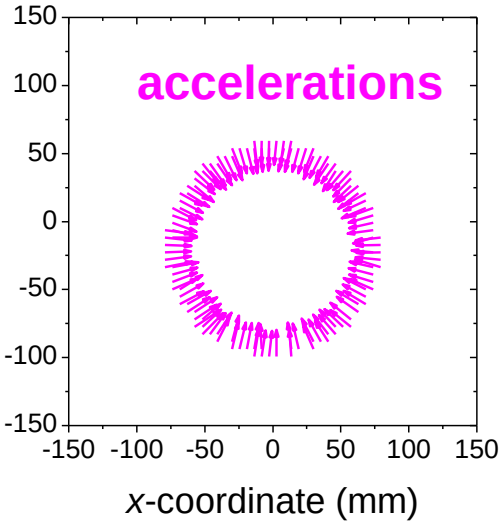
Rotating tracer: near centre of HR++ scanner



Labelled with 47 kBq of ^{68}Ga and rotating in the *x*-*y* plane at 106 rpm at *r* = 77 mm







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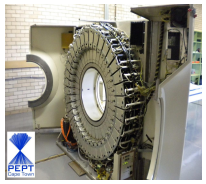
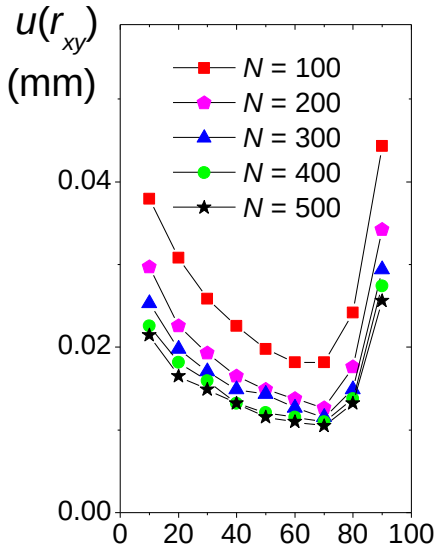
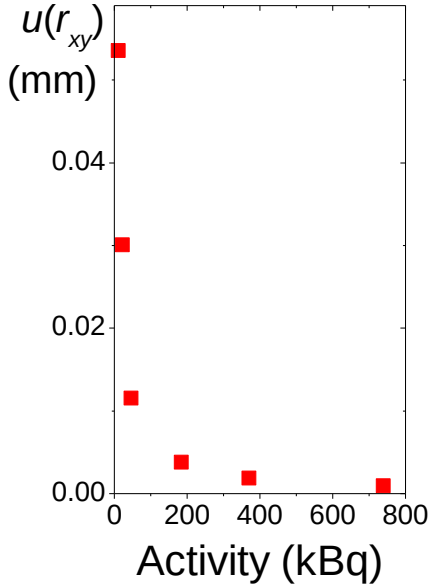


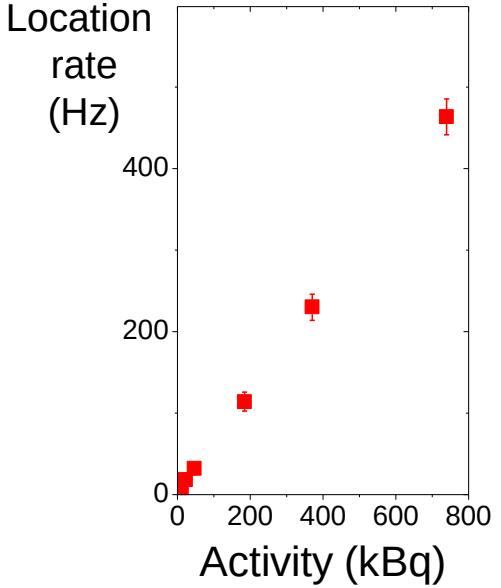
Rotating tracer: near centre of HR++ scanner

Labelled with ^{68}Ga (10 to 740 kBq) and rotating at 106 rpm at *r* = 77 mm

$$u(r_{xy}) = \sqrt{\frac{\sum(\Delta r_i)^2}{n}}$$







***f* = 70%, *N* = 400**

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Conclusion

Positron emission particle tracking is a novel metrological application of PET radioisotopes.

Research at PEPT Cape Town is benefiting from cooperation and collaboration between physics, chemical engineering, nuclear chemistry, medical imaging and the minerals industry.

Advances are being made on four fronts:

PEPT metrology
Tracer development
Fundamental flow studies
System-specific studies

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Conclusion: outlook

… physics limitations of PEPT.

… uncertainty budget for PEPT.

… a program of research into the labelling of small (sub 50 micron particles) is in progress at iThemba LABS cyclotron facility.

… also the potential to label a greater variety of “realistic” particles for PEPT.

… this will lead to possibilities of applying PEPT to systems of “liquid” and “gaseous” flow, such as in froth flotation.

… we are also planning the fusion of PEPT measurements with fast neutron radiography images of the bulk (in steady state motion).

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