Industrial applications of radioactivity

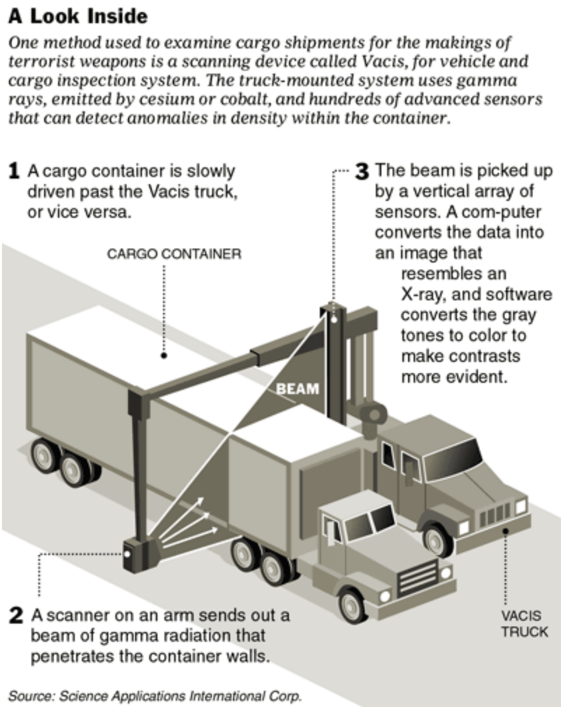
Gamma-ray radiography

Use to inspect welds, pipelines, etc

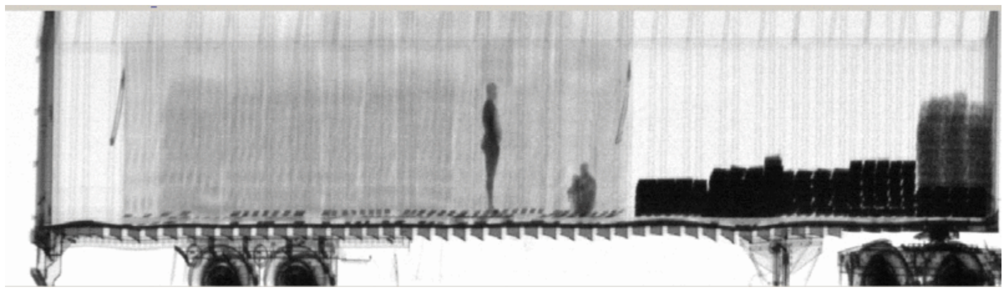
Usually ^{60}Co (5 years, 1.2 MeV γ - penetrates 20cm steel)

or ^{192}Ir (74 days, 0.38 MeV γ – penetrates 7 cm steel).

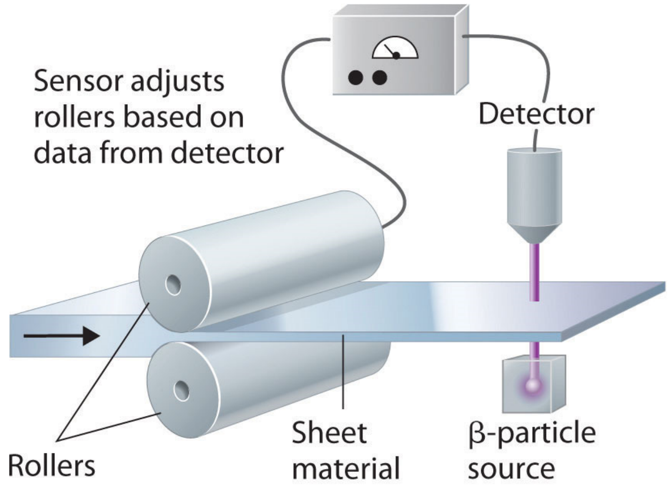
Also used for cargo inspection:



Co-60 image of stowaways

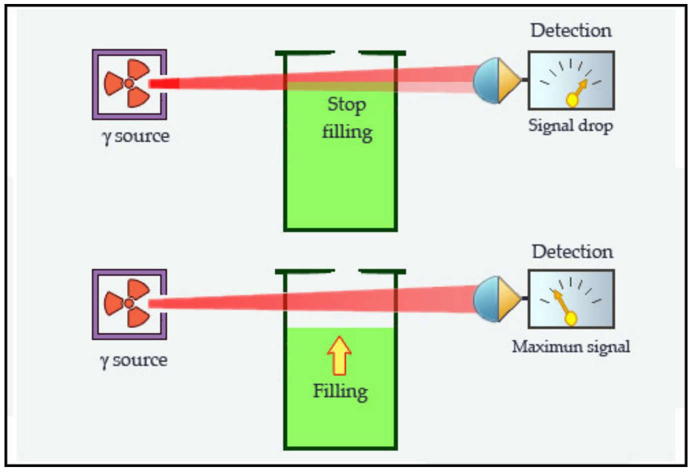


Gamma-ray attenuation also used as **thickness gauge** for monitoring/controlling manufacture of ribbons: e.g. paper (betas), rolled steel (^{241}Am etc)

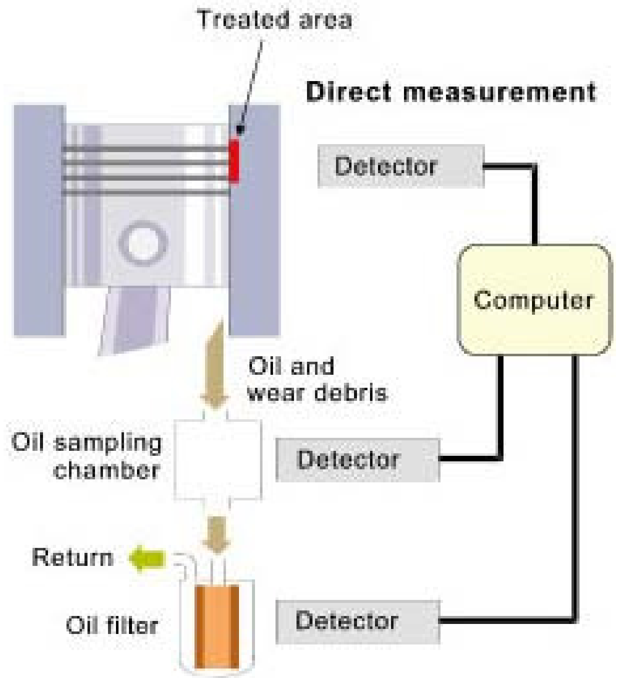


or monitoring material on conveyors (^{60}Co used in mining)

Also as depth gauges



Thin Layer Activation



For measuring **wear** on components
(especially automotive parts, for R&D):
irradiate surface with beam from accelerator to create long-lived radionuclide in well-defined surface layer (typically ~ 50μm deep).
Subsequently monitor surface removal by detecting gamma-rays either from remaining layer or from wear debris

Steel:

- $^{56}Fe(p,n)^{56}Co$ (77 days, 0.85 MeV and 1.24 MeV gammas)
- $^{56}Fe(d,n)^{57}Co$ (270 days, 0.122 MeV gammas)
- Might activate different surfaces with each for simultaneous studies

Aluminium

- Best probably $^{27}Al(^{3}He, 2\alpha)\,^{22}Na$ (2.7 years, 0.511 MeV and 1.27 MeV gammas)

Diamond-like carbon (DLC) coatings

- $^{12}C(^{3}He, 2\alpha)\,^{7}Be$ (53 days, 0.47 MeV gamma)

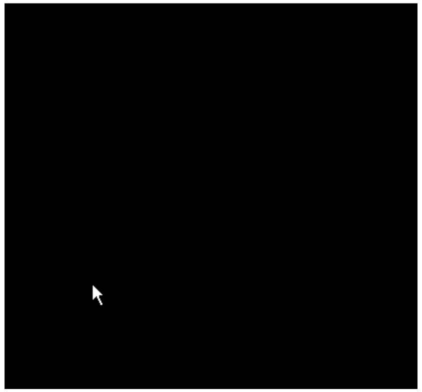
Tracer techniques

Especially imaging (similar to Nuclear Medicine):

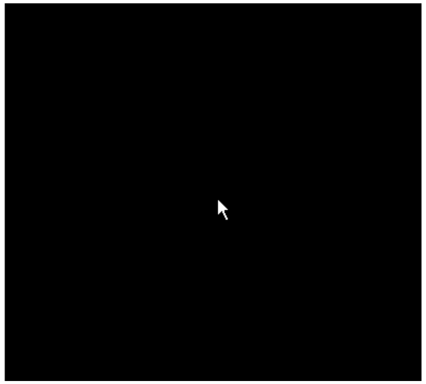
PET

- 511 keV photons penetrate steel
- can see inside real industrial plant
- Can label and track one component of multi-phase flow

BUT slow

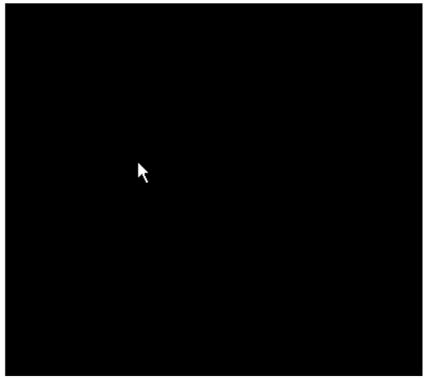


Initial loading



5 revs

10 revs



20 revs

PET study of pharmaceutical powder blending

Stop/start: each image is 2x15 minutes, giving 60x6mm slices

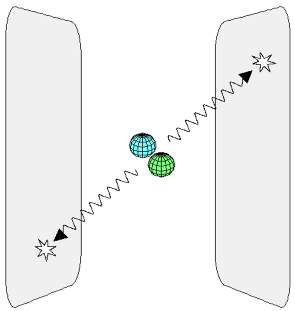
Images can be analysed to give quantitative measures of mixedness

Gamma rays are penetrating – can observe labelled fluid inside process vessels

But PET is slow – requires detection of ~ million coincidence pairs

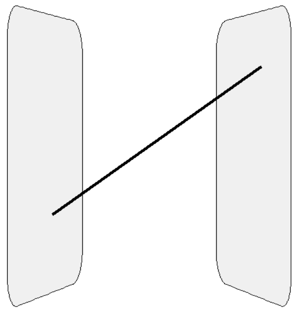
For fast dynamic information use **Positron emission particle tracking (PEPT):**

Introduce a single labelled particle, and locate it frequently



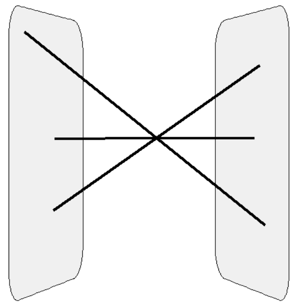
Detection

Detection of gamma rays using two large position sensitive detectors.



Reconstruction

Two rays detected in coincidence define line along which particle lies.



Particle Location

After several events, tracer can be located via triangulation.

Currently labelling tracer particles down to 50μm diameter

Can locate tracer particle to within 1mm every 1ms

Some history

1984 First Birmingham positron camera developed for industrial PET

(studying aero engines with Rolls Royce)

1987-93 Development of PEPT [*Parker et al, NIM **A326** (1993) 592-607*]

1999 New Birmingham positron camera – data rate improved 20x

2004 New Cyclotron operational

2003- Development of modular positron cameras

(using components from redundant medical PET scanners)

2006 First PEPT study performed on an industrial site

1996-2003 Delft positron camera developed and used for PEPT

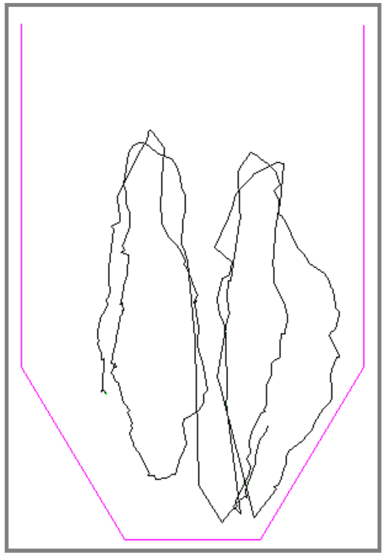
2003(?) Hoffman performed PEPT using PET scanner in Groningen Hospital

(studying small fluidised bed) [*Hoffman et al, MST **16** (2005) 851-858*]

2009- Hoffman doing PEPT at Bergen

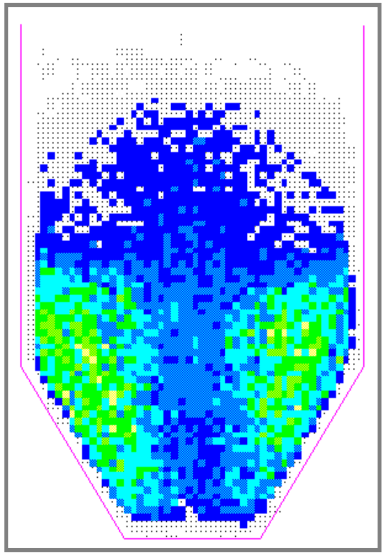
2009 PEPT Cape Town opened at iThemba Labs, South Africa

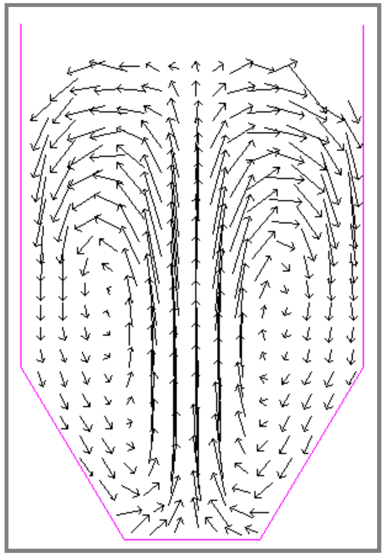
PEPT data from spouted fluidised bed



A typical particle track This track represents five seconds worth of particle motion within a spouted fluidised bed.

The amount of time spent by the particle within a particular region of the bed, or *occupancy*, can be related to the density of the bulk.

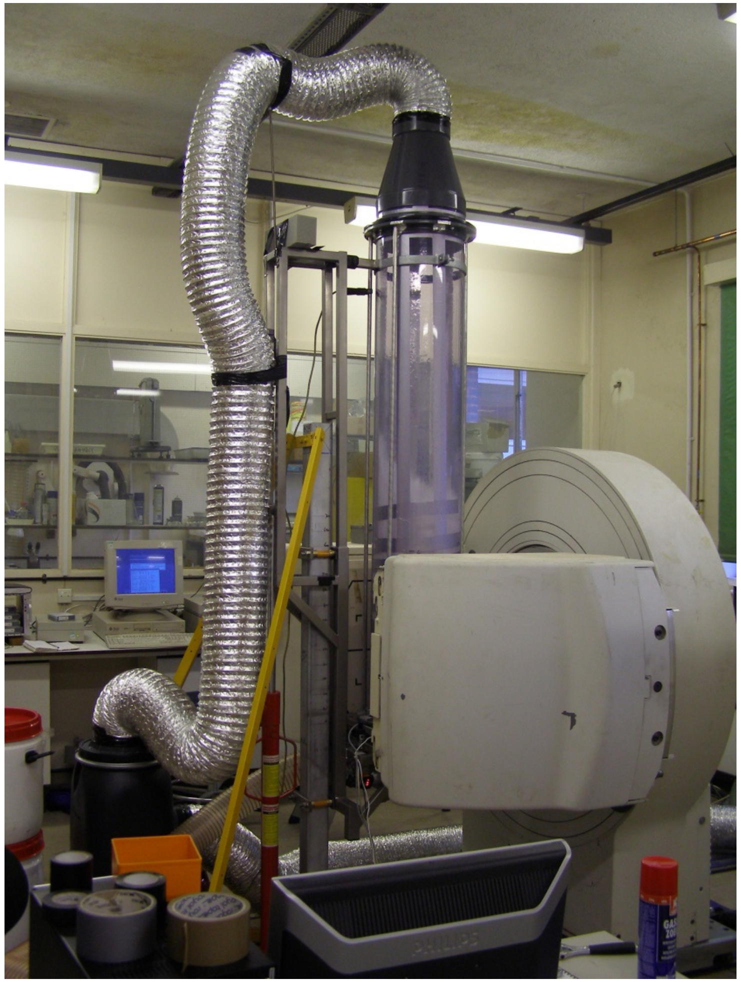




Analysis of the particle track allows production of vector plots.

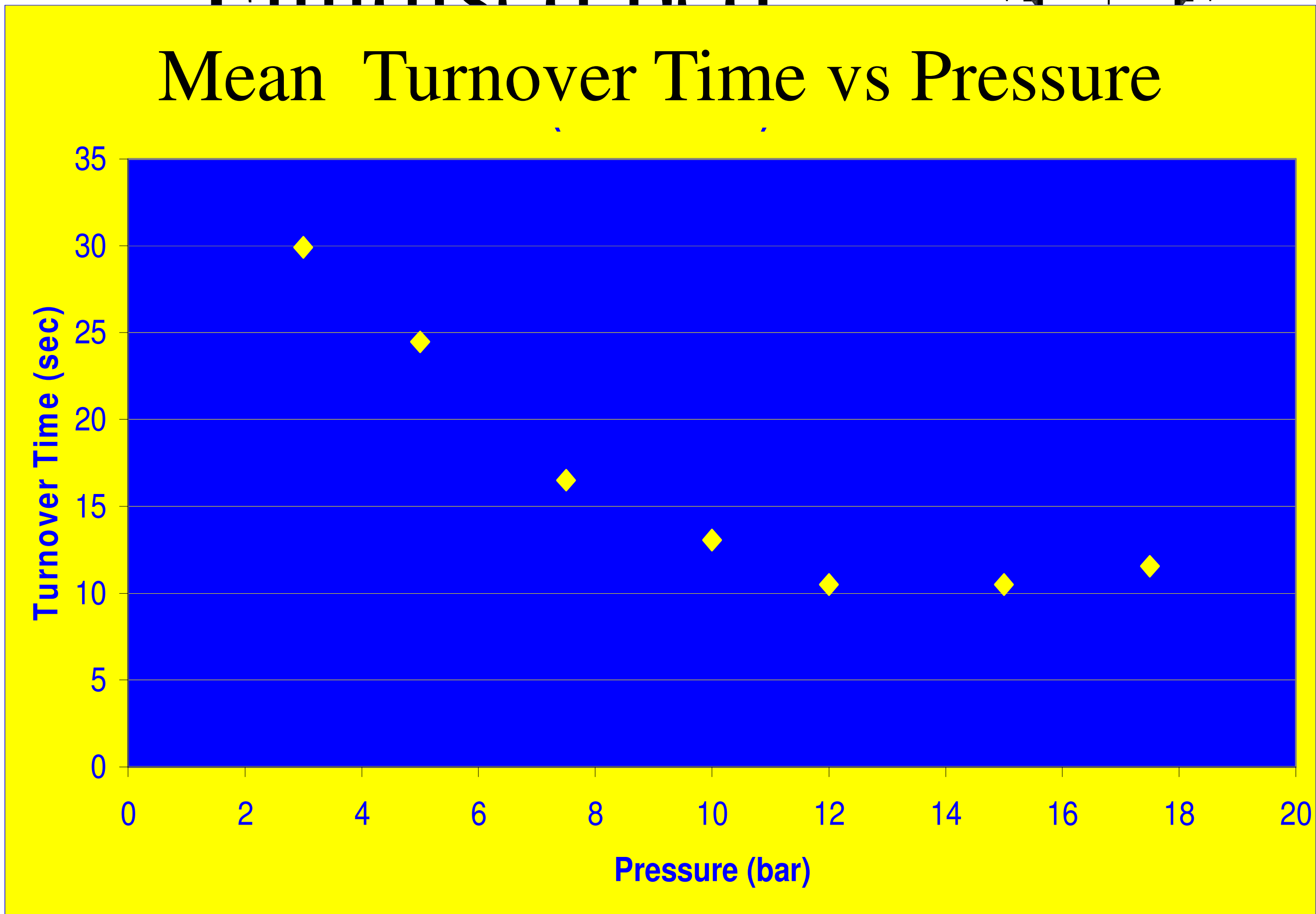
Examples of standard PEPT

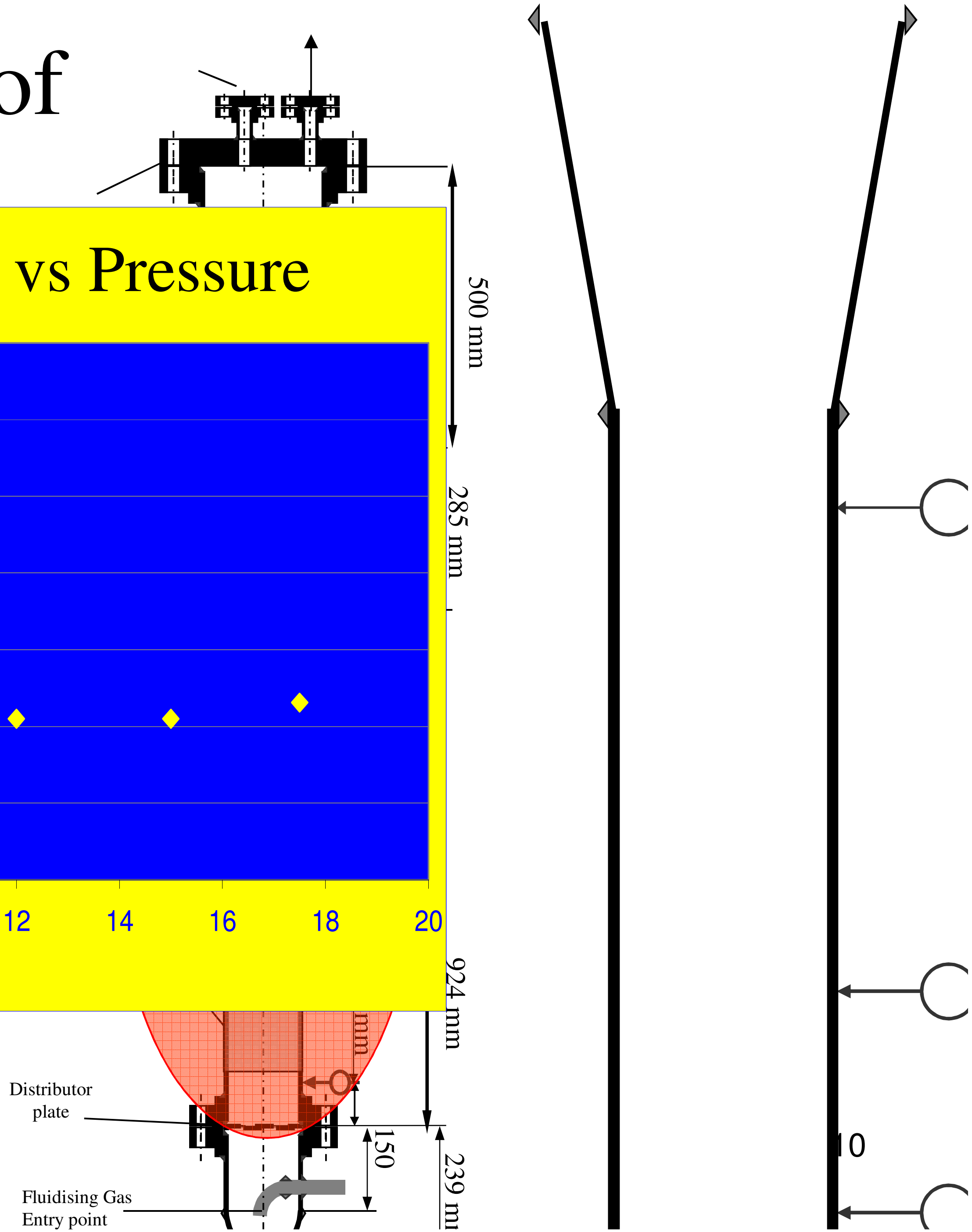
Scraped-surface heat exchanger



Fluidised bed

Eg: PEPT study of Fluidised bed





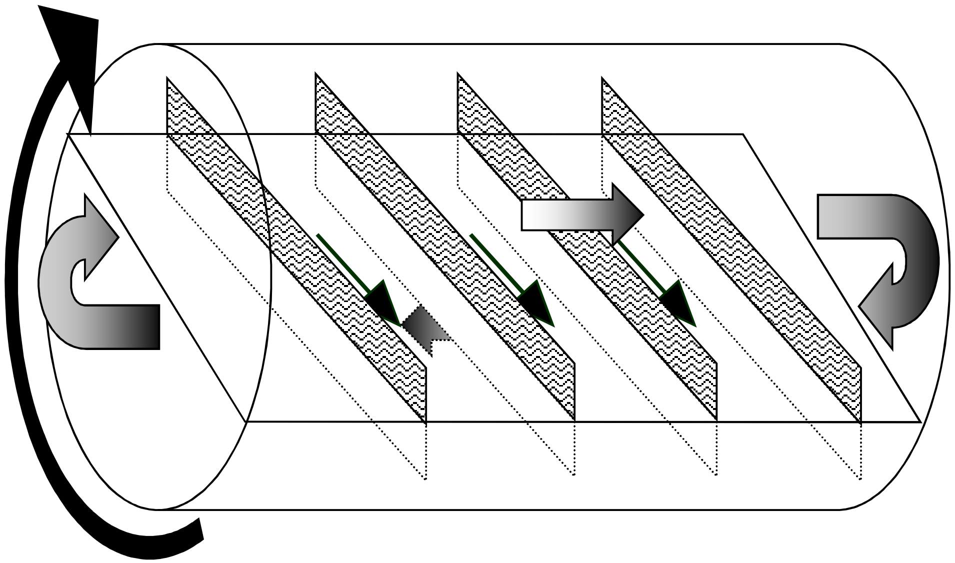
- 0.5mm polymer tracer
- Determine circulation time etc

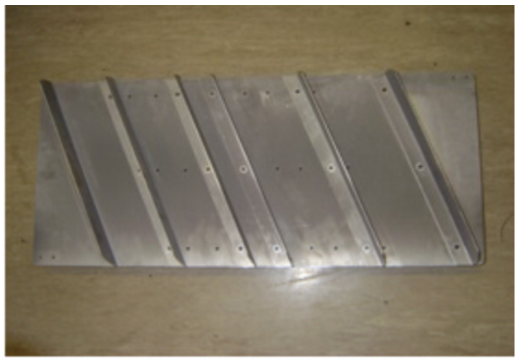
Batch Operated Grain Roasting Drum

LOW SPEED

Baffled Drum

Kunii et al, Powder Technology 96 (1998) 1

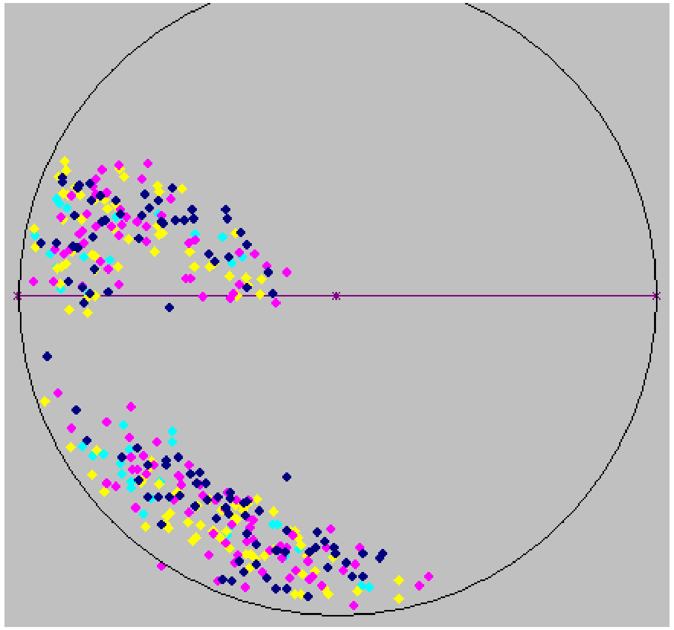




Transaxial motion:

Superimpose many tracks,

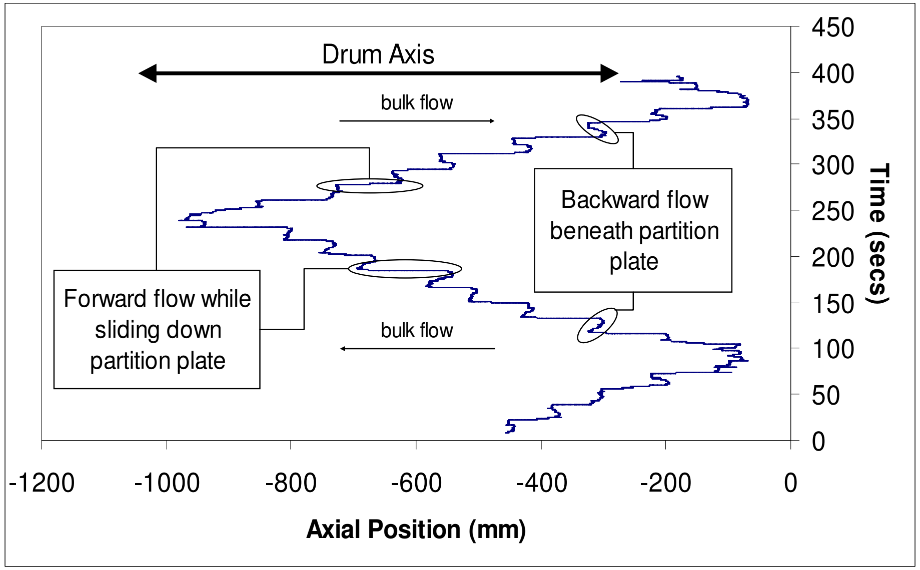
related to motion of baffle

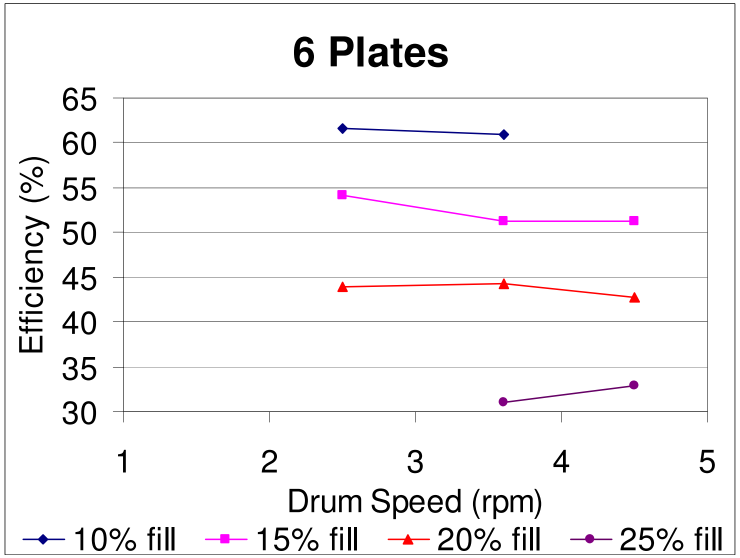


Axial motion

(followed tracer over 1m length drum

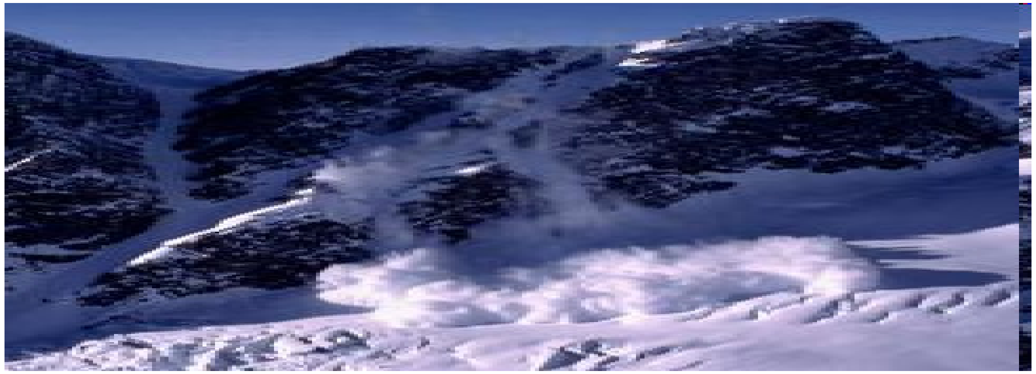
using positron camera on rails)





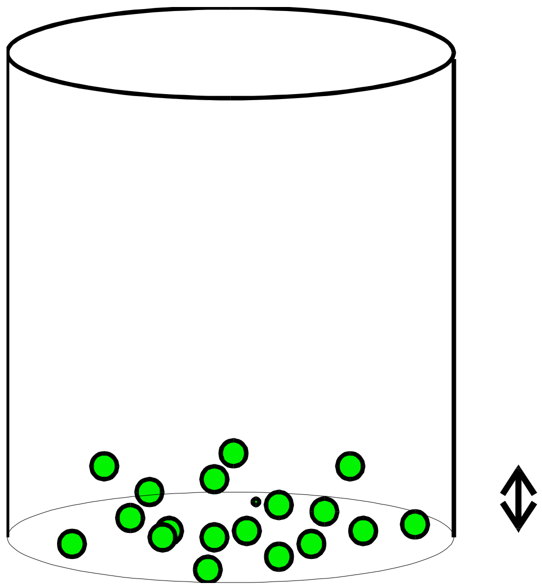
Determine transfer probability per revolution

Granular material: important in nature…



…and industrially:

PEPT studies of granular gases



Few particles, collisions well separated

Determine number density,

bulk motion (convection),

granular temperature

self diffusion

PRL 111, 038001 (2013) PHYSICAL REVIEW LETTERS week ending 19 JULY 2013

Thermal Convection and Temperature Inhomogeneity in a Vibrofluidized Granular Bed: The Influence of Sidewall Dissipation

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[2]*Multi Scale Mechanics (MSM), MESA +, CTW, University of Twente, Post Office Box 217, 7500 AE Enschede, The Netherlands*
(Received 16 February 2013; published 16 July 2013)

Using a vertically vibrated, fully three-dimensional granular system, we investigate the impact of dissipative interactions between the particles in the system and the vertical sidewalls bounding it. We find that sidewall dissipation influences various properties of the bed including, but not limited to, the spatial distribution of granular temperatures, the functional form of velocity distributions, and the strength of convection. Simple, monotonic relationships are observed for all the aforementioned properties, including a striking linear relationship between convection strength and wall dissipation. We conclude that sidewall effects are not limited to the vicinity of the walls themselves, but extend into the bulk of the system and hence must be considered even in relatively wide, three-dimensional systems. We also propose the possibility of using the alteration of sidewall material as a method of "tuning" certain system parameters in situations where changing the bulk properties or driving parameters of a granular system may be undesirable.

DOI: 10.1103/PhysRevLett.111.038001 PACS numbers: 45.70.Mg, 47.20.Bp, 81.05.Rm

Tracers for PEPT

Cyclotron is used to make positron-emitting nuclides such as
F-18 (110 min), Cu-61 (3.4 hr), Ga-66 (9 hr), Cu-64 (12 hr)

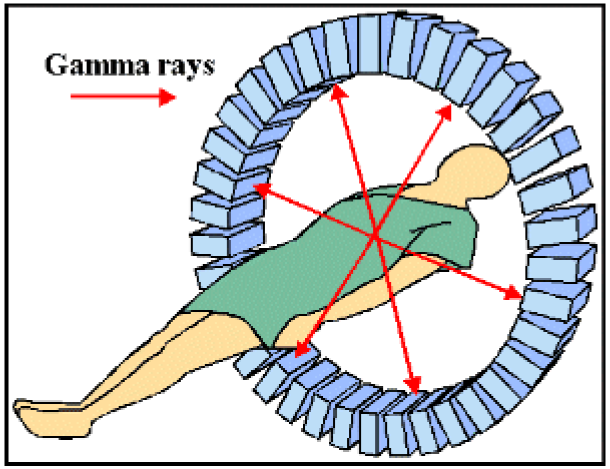
Some larger refractory particles (silica, alumina) are directly irradiated

Mostly, activity is produced and then adsorbed onto particles

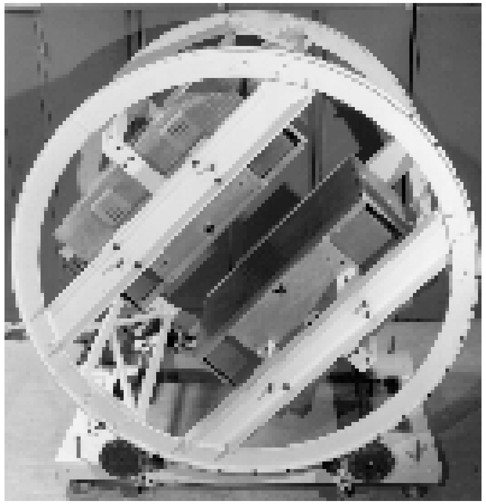
Can label many materials down to 50µm

Detector systems for PEPT

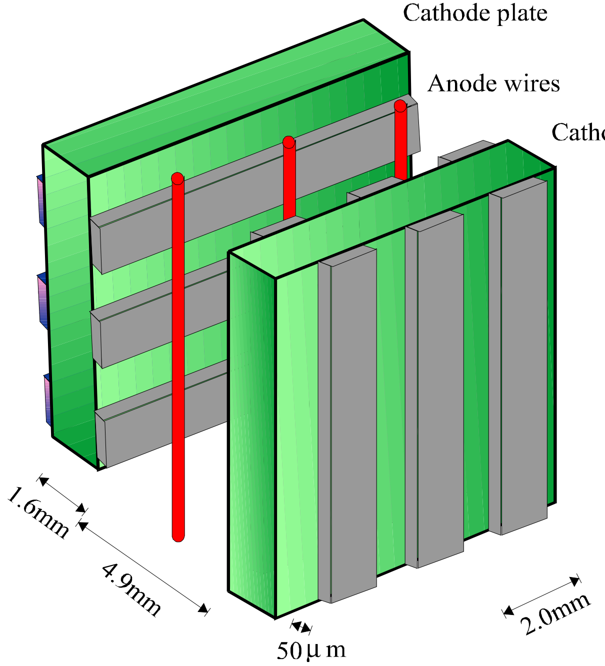
- PET scanner/Positron camera



Original Birmingham Positron Camera



- Originally designed to image lubricant in operating jet engine
- Operational 1984
- Pair of gas filled MWPCs, sensitive area 600x300mm^2



- Cathode planes have 50µm lead strips
- Delay line readout
- Each chamber contains a stack of 20 such assemblies
- Total quantum efficiency for 511keV photons 7%

- Spatial resolution 8mm FWHM (+long tails)

Useful count rate limited to around 3000 events/s due to

dead time in readout

random coincidences (resolving time 12.5ns)

“New” Birmingham Positron Camera

- Installed summer 1999
- Commercially available medical system (ADAC Forte)
- Cost £0.3M
- Pair of gamma camera heads on rotating gantry; separation 250-800mm

Each head contains NaI(Tl) crystal 590x470x16mm^3,
55 PMTs each connected to its own ADC;
single board computer

	Old camera	New camera
Spatial resolution	8mm	4-6mm
Singles sensitivity	7%	23% total/16% photopeak
Energy resolution	None	15% FWHM
Resolving time	12.5ns	7.5ns
Max true coincidence rate	5kcps	100kcps

Third generation Birmingham systems

developed from redundant medical PET scanners

Since 2002 PIC has acquired

4 complete PET scanners

and components from two others

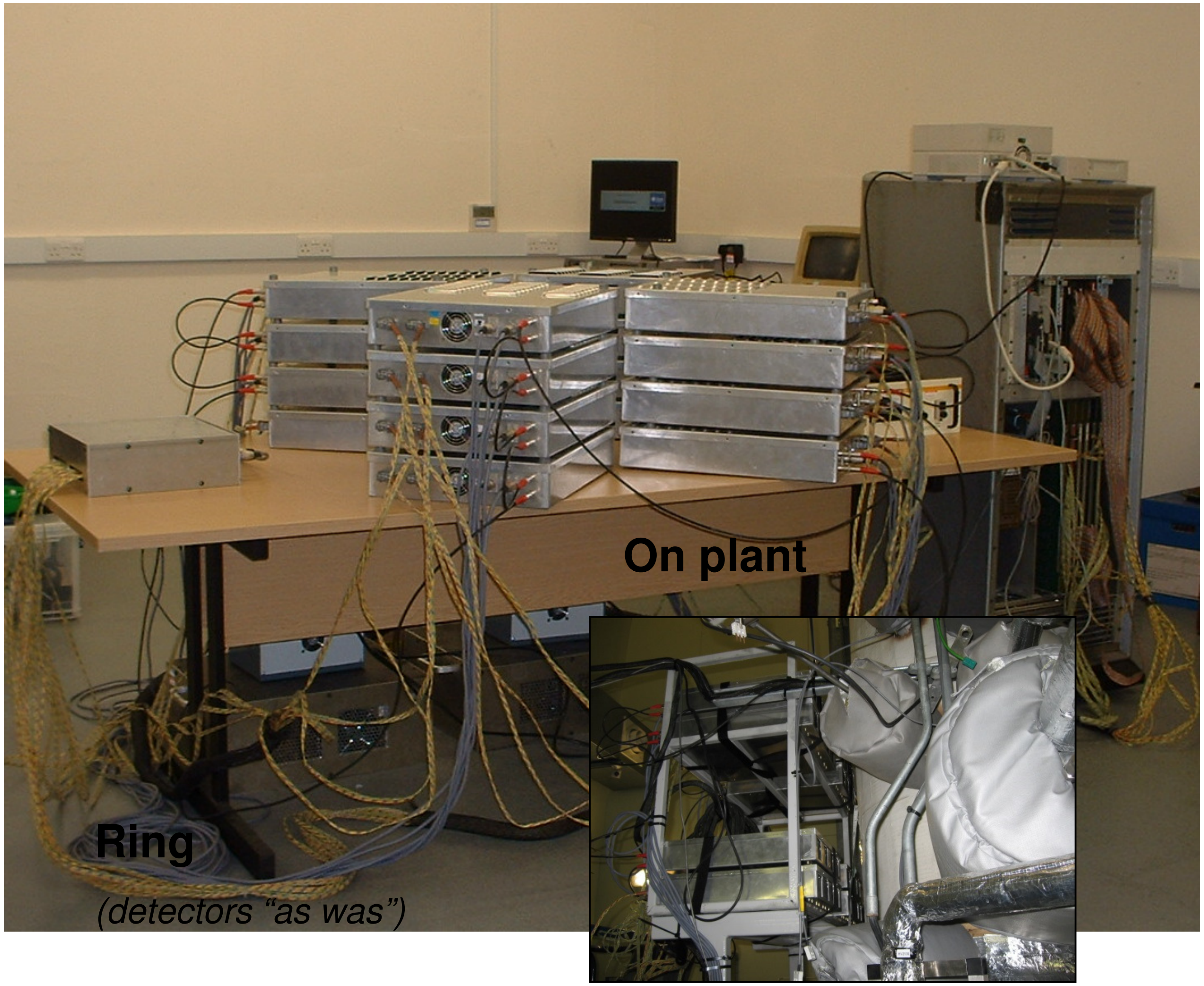
These are inherently modular, and can in principle be reconfigured in different geometries.

Some are being used/developed for PET (uniform rings)

and others for PEPT

Transportable Modular Positron Camera for PEPT

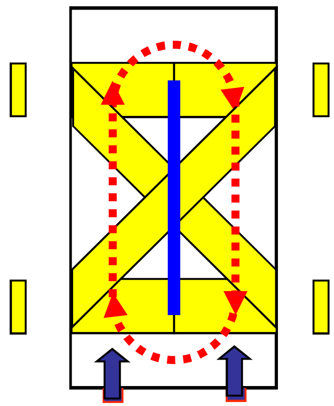
16 detector modules (extendable to 32)



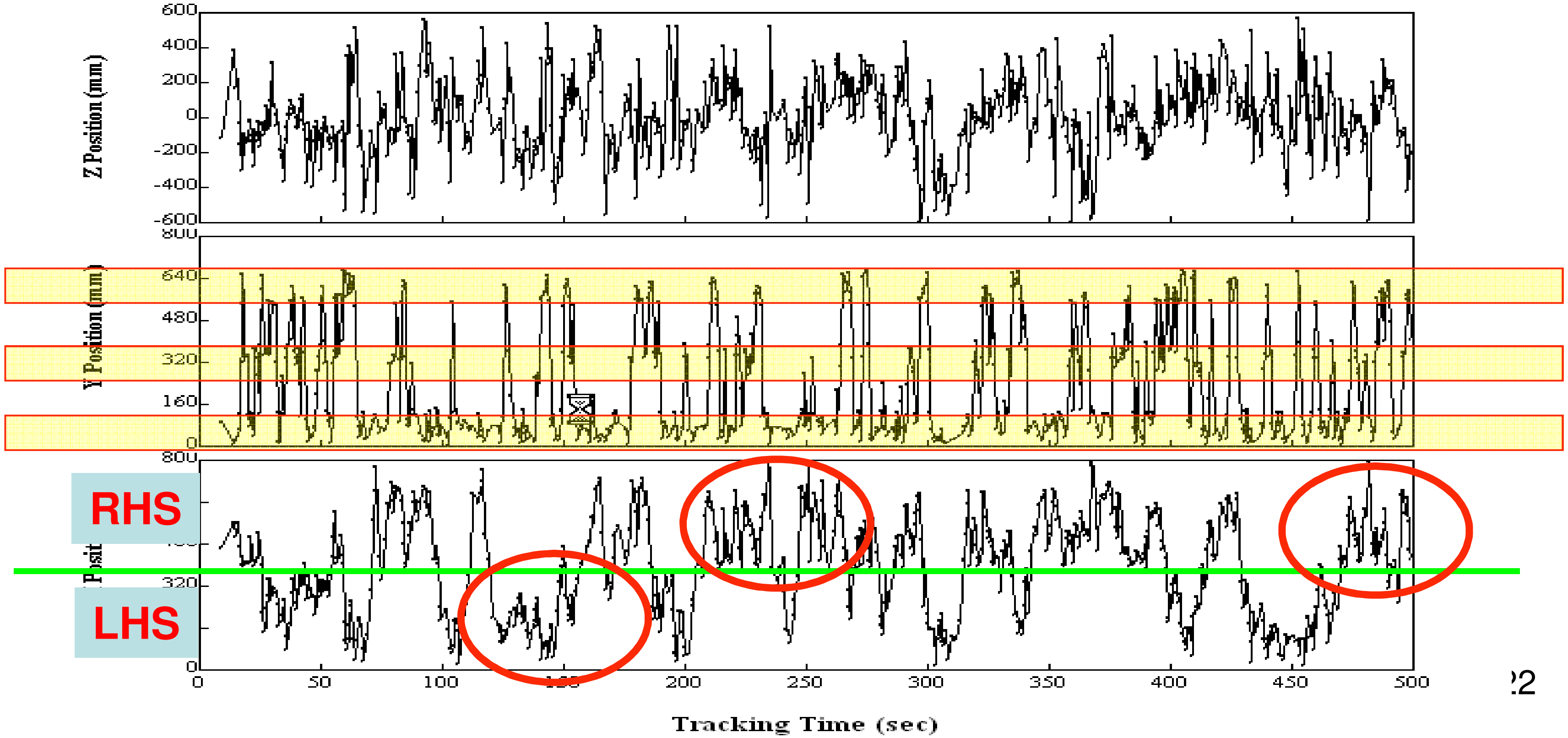
On-plant PEPT study : BP, Hull

(240km from Birmingham)

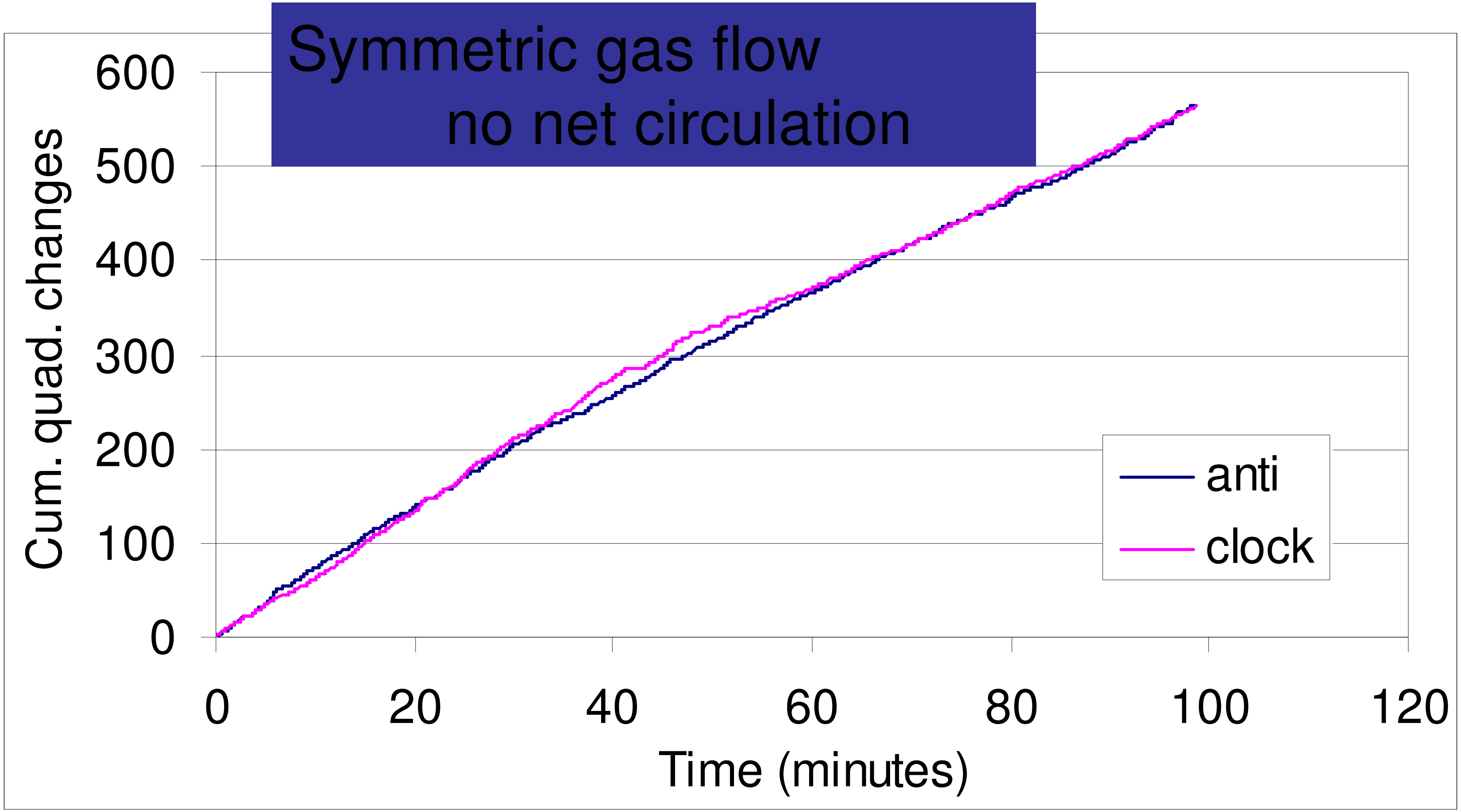
750mm diameter fluidised bed, with central dividing baffle + different air supplies each side of baffle

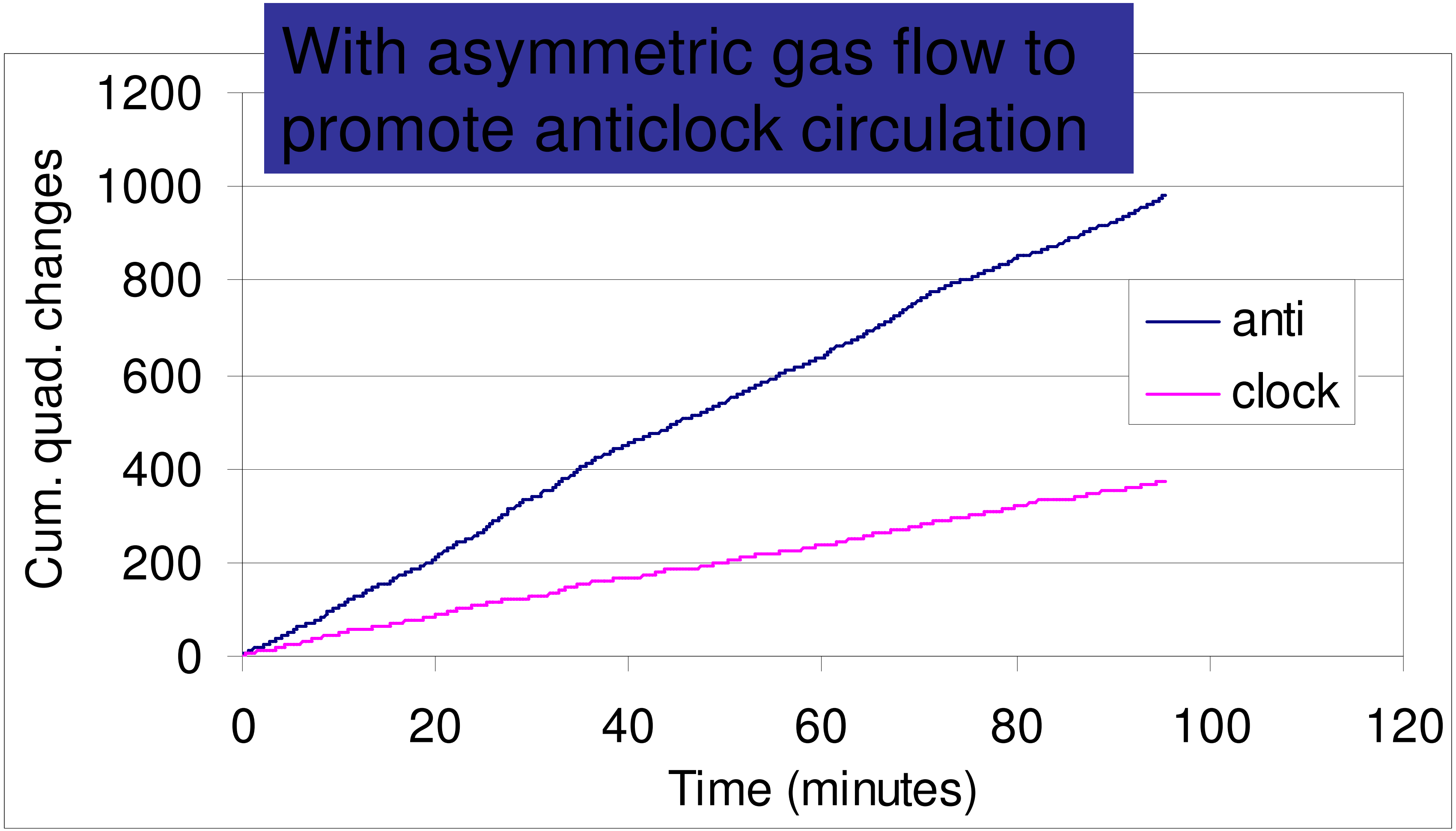


4 banks of detectors (detector separation 1.2m) give FOV show

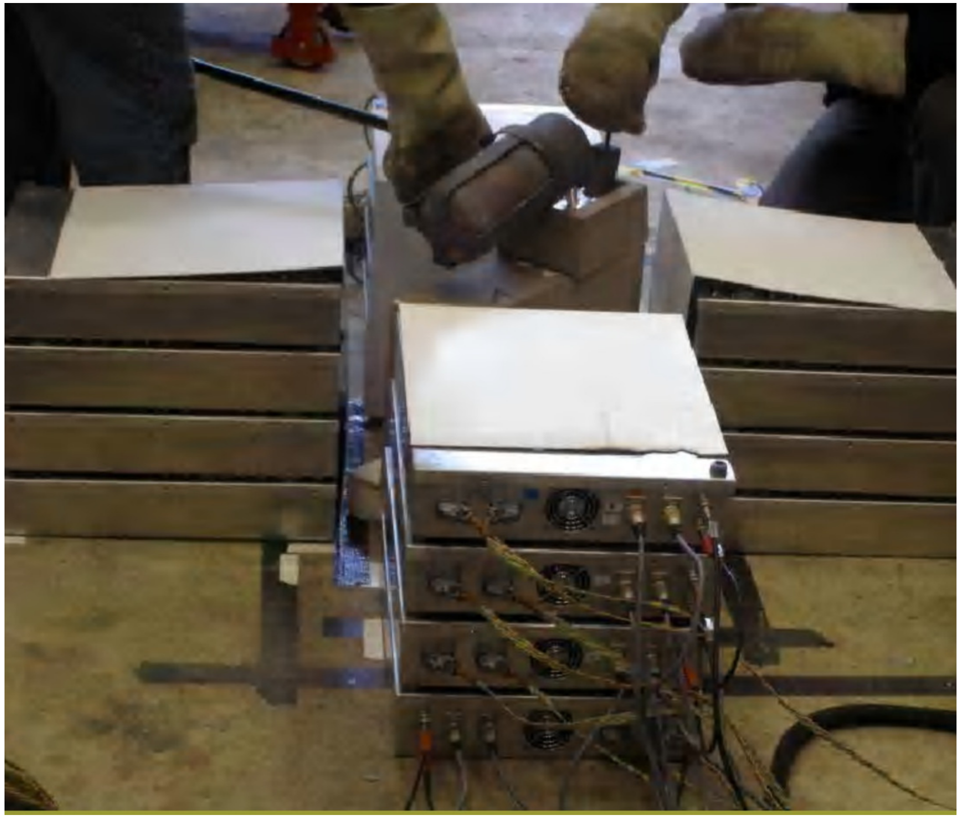


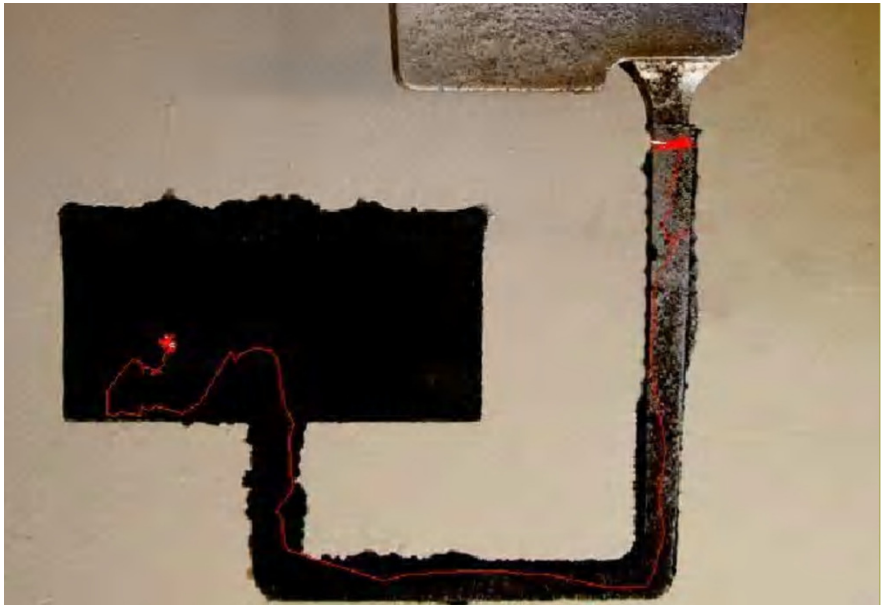
Analysis in terms of movement between four quadrants



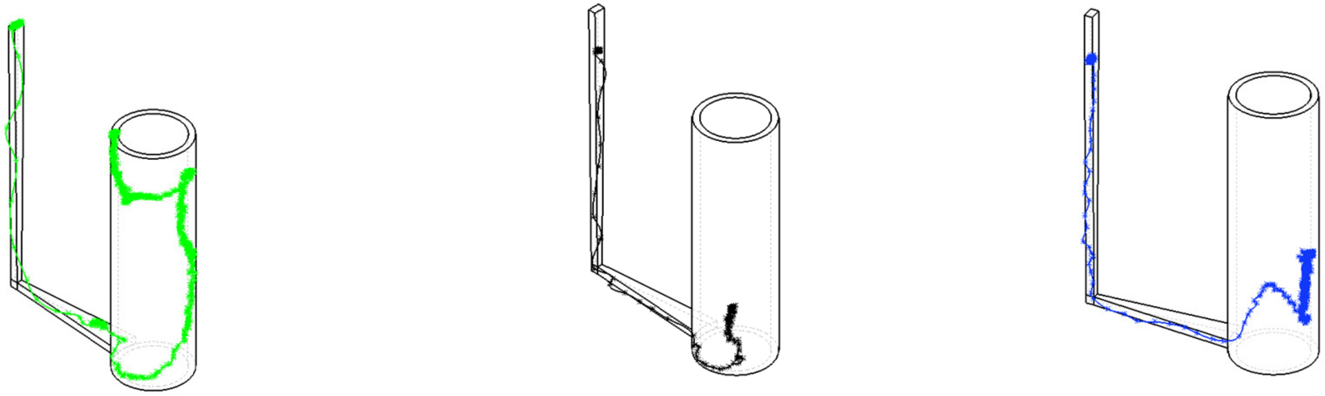

With asymmetric gas flow to promote anticlock circulation
Cum. quad. changes
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
Time (minutes)
anti
clock

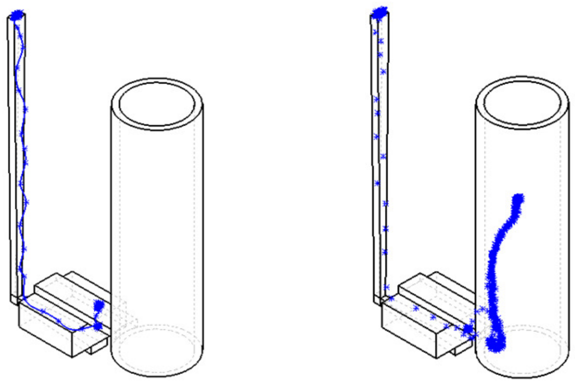
Casting of liquid metal:
PEPT tracking of small alumina inclusion





Examples of tracks obtained with entrained alumina particles of size range 63-100 µm





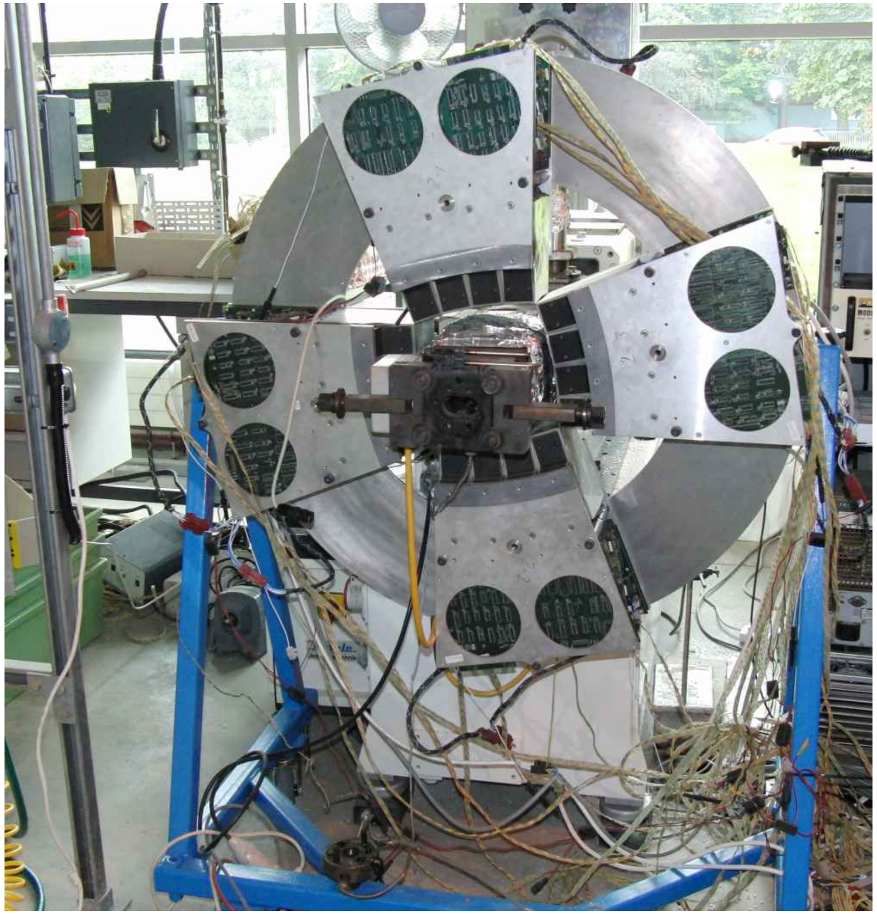
Examples of the use of PEPT to study filtration of liquid metal using ceramic foam filte
In (a) the alumina particle has become trapped in a 30 ppi filter.
In (b) the alumina particle has passed through a 20 ppi filter.

EU Peptflow project **http://www.peptflow.com/**

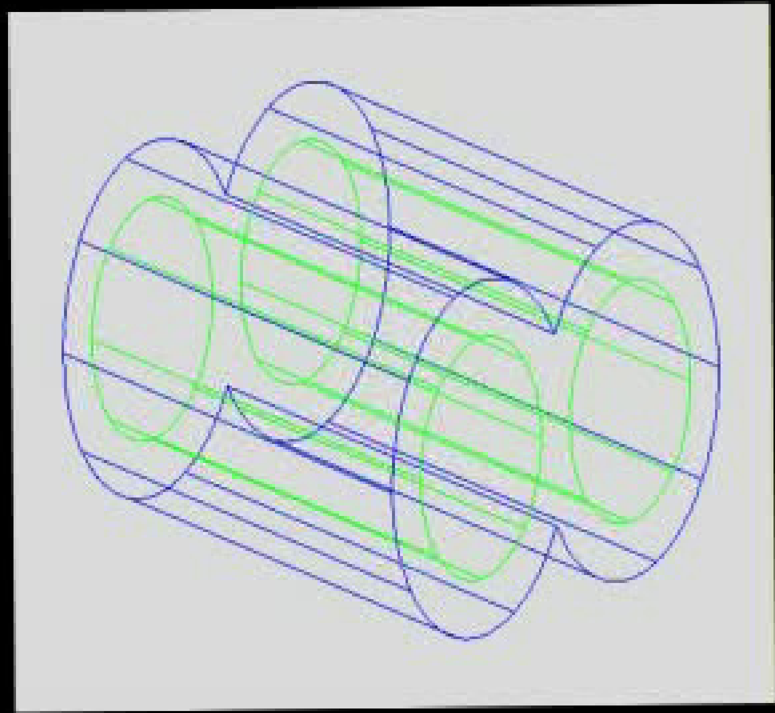
Twin Screw Extrusion of Polymers

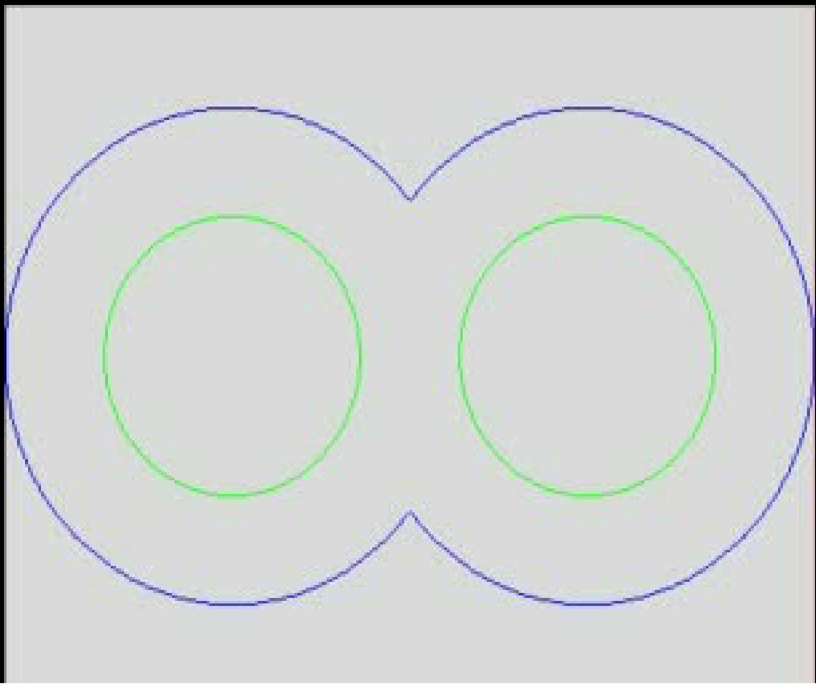
Modular camera with 32 blocks in 2 rings. New PC-based data acquisition system gives data rate > 1MHz

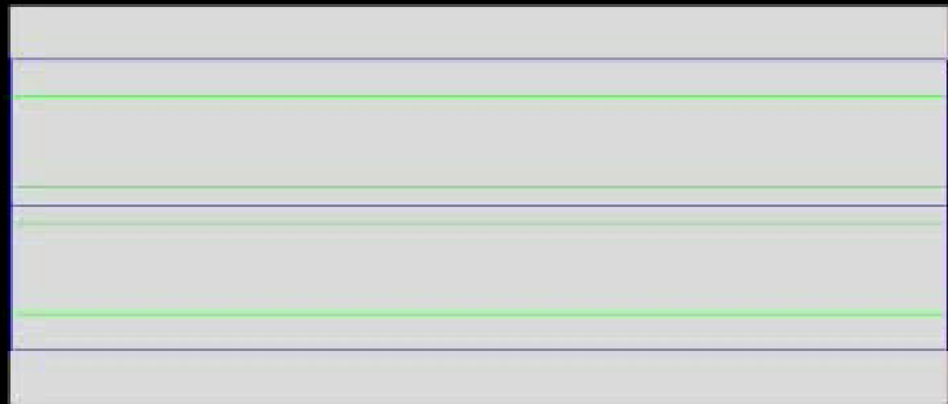
(Andy Ingram, Tom Leadbeater)



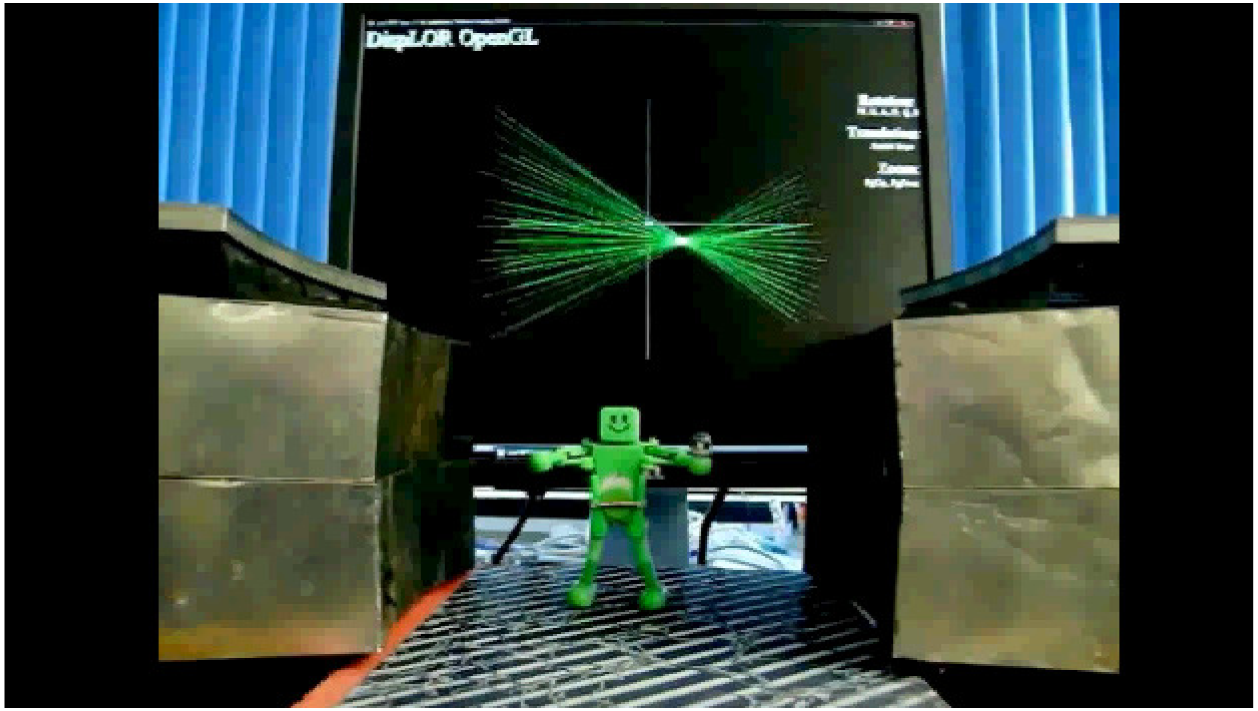
PEPT - FLOW





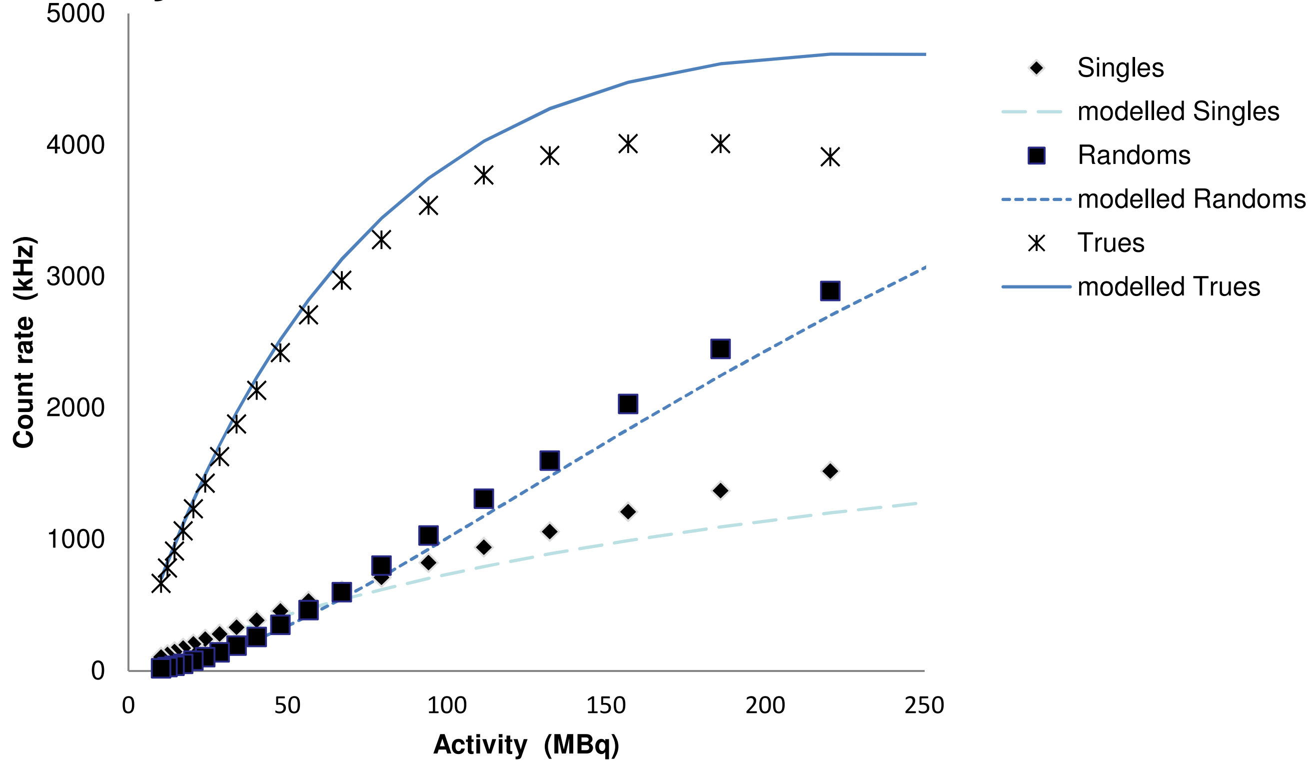


Simple demo system



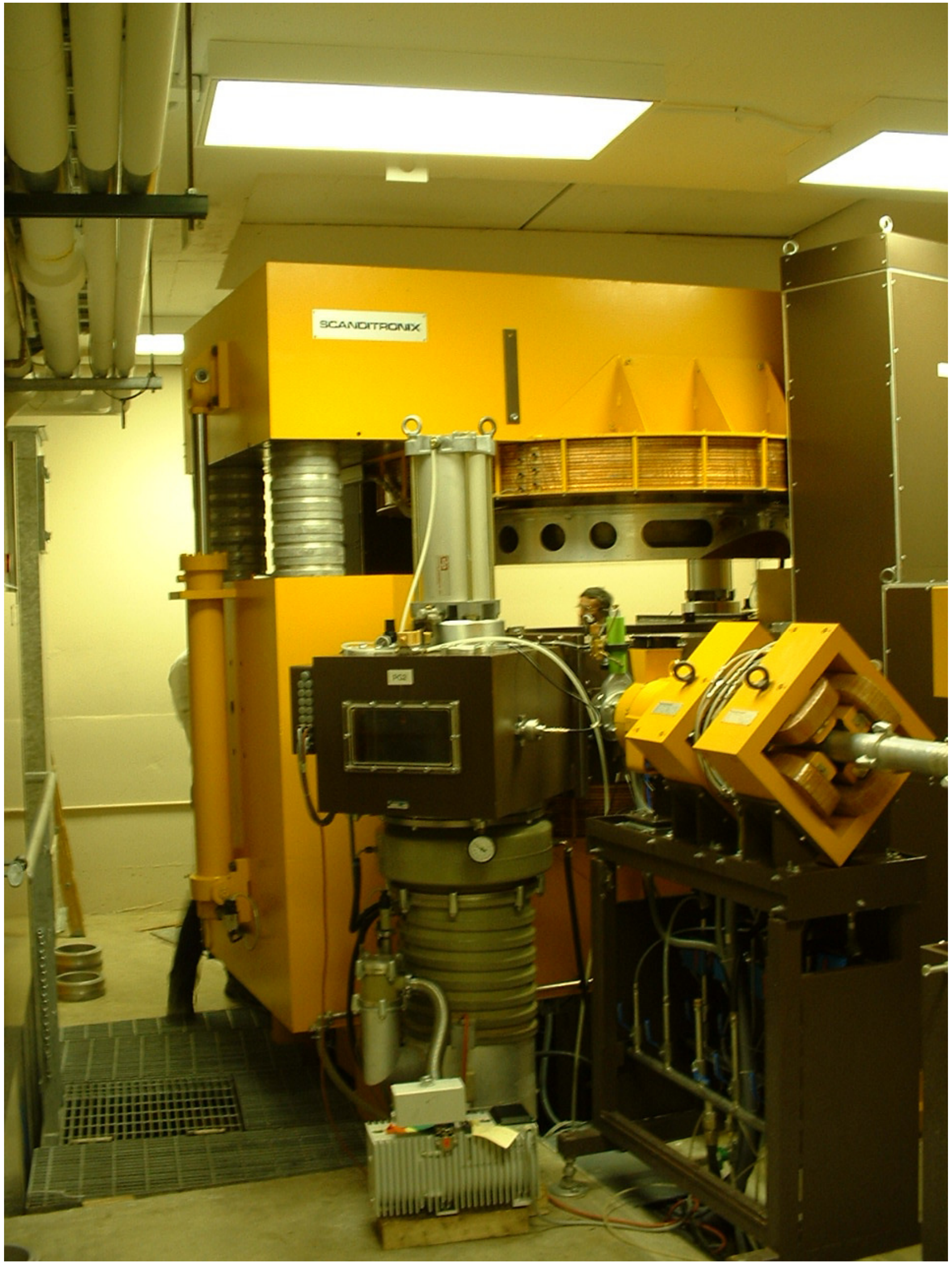
The future? Ecat HR+

288 detector blocks (36x38x30 mm^3) in 4 rings:
32 rings each of 576 detector elements
Block efficiency ~ 0.66



Trues rate up to 4 MHz (mainly due to low dead-time)

iThemba scanner is HR++ with 6 rings – should be capable of over 7MHz datarate


SCANDITRONIX

Cyclotron was packed into 56 crates

- 3 40 foot containers + 2 20 foot containers

Travelled by rail to Montreal and thence by sea to Liverpool where it arrived on 24th July 2002

After clearing customs, arrived in Birmingham 20-23 August

“Active components” were packed in Type A drums and sent air freight

Construction of new supporting floor complete February 2003

Ring Road
Medical School
Ring Road
North
South West
Campus
ALLELY'S TRANSPORT
STUDLEY, WARK'S ENGLAND.
01527-852408
01527-853298
TOP

Cyclotron has been operational since early 2004

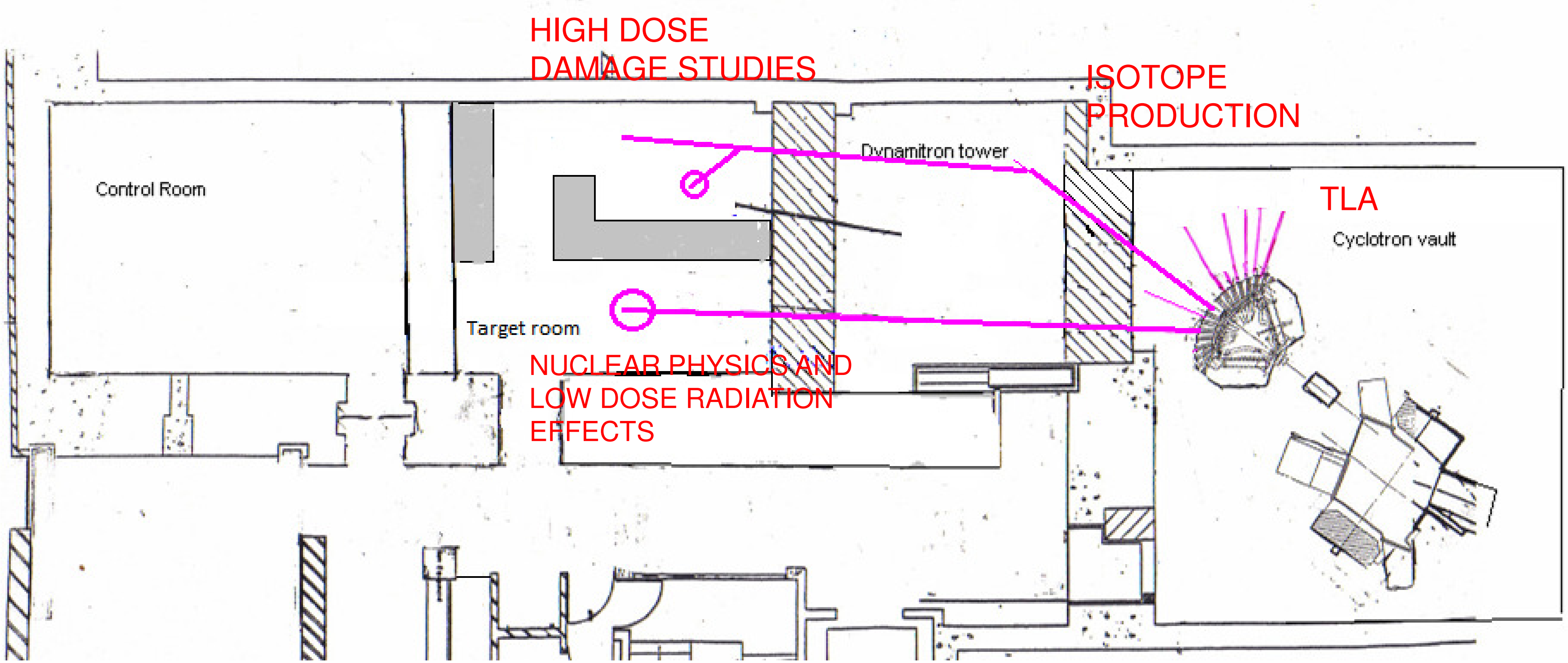
p 11-39 MeV and 3-9 MeV (N=2)
d 5.5-19.5 MeV
α 11-39 MeV
^3He 33-54 MeV and < 27 MeV

Also 46 MeV $^{14}N^{4+}$ and 70 MeV $^{14}N^{5+}$

for nuclear physics

In 2005 we added a 12-way switching magnet (blue) [ex Vivitron]

More recently, we were asked to provide high dose-rate damage studies (LHC ATLAS group and metallurgy) so extended a second beam-line into a specially shielded area.



Cyclotron is used for

- Producing positron emitting nuclides for Engineering PET [NOT FDG]
- Producing ^{81}Rb for ^{81m}Kr generators
- Thin Layer Activation
- Other isotope production:
  - ^{69}Ge for labelling oil
  - ^{62}Zn, ^{64}Cu supplied to St Thomas' Hospital London
  - Various irradiations for NPL
- Radiation effects studies:
  - Radiobiology + dosimetry (proton imaging)
  - Space electronics etc
  - ATLAS components
  - Metallurgy of nuclear materials
- Nuclear physics (student projects)