Positron emission particle tracking using a modular positron camera

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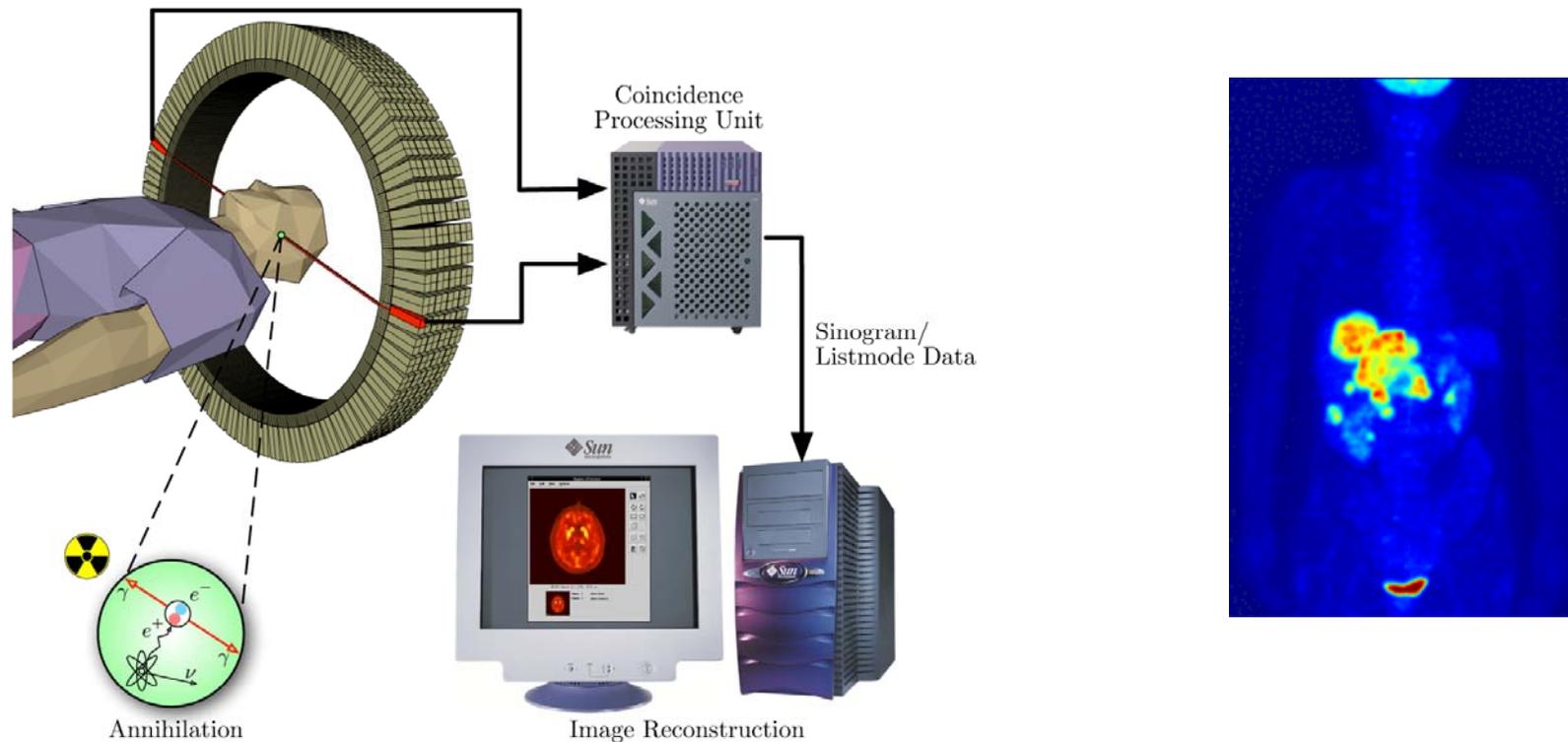UNIVERSITY OF BIRMINGHAM **Positron Imaging Centre**

Positron emission tomography (PET):

Mapping concentration of radioactively-labelled fluid

PET scanner consists of rings of many small detectors, operating in coincidence to detect the pairs of back-to-back γ-rays from positron annihilation.

After detecting millions of such events a 3D tomographic map of tracer concentration can be reconstructed

Coincidence Processing Unit

Sinogram/ Listmode Data
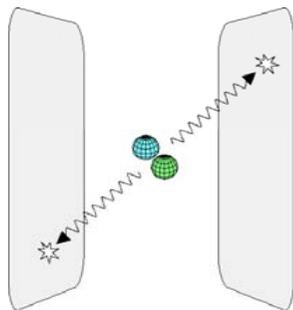
Annihilation

Image Reconstruction

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

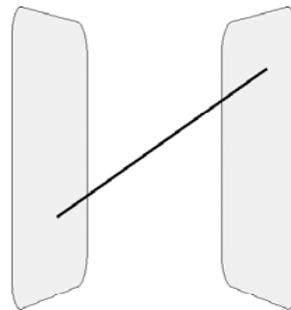But PET is slow – requires detection of ~ million coincidence pairs

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

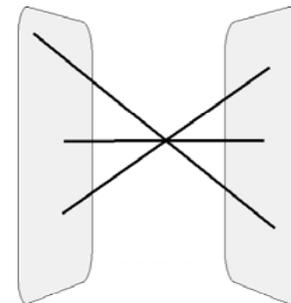Introduce a single labelled particle, and locate it frequently

Detection

Detection of gamma rays using two large position sensitive detectors.

Reconstruction

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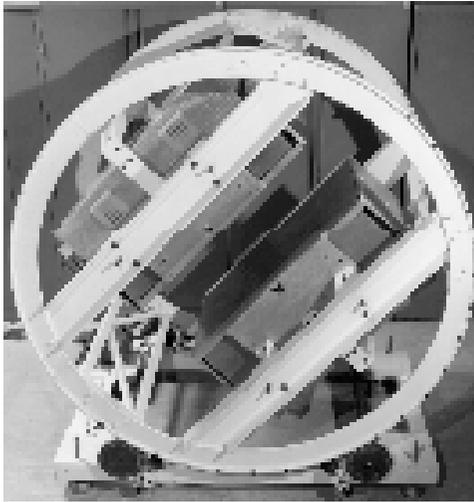
Particle Location

After several events, tracer can be located via triangulation.

Currently labelling tracer particles down to 100µm diameter

Can locate tracer particle to within 1mm every 1ms
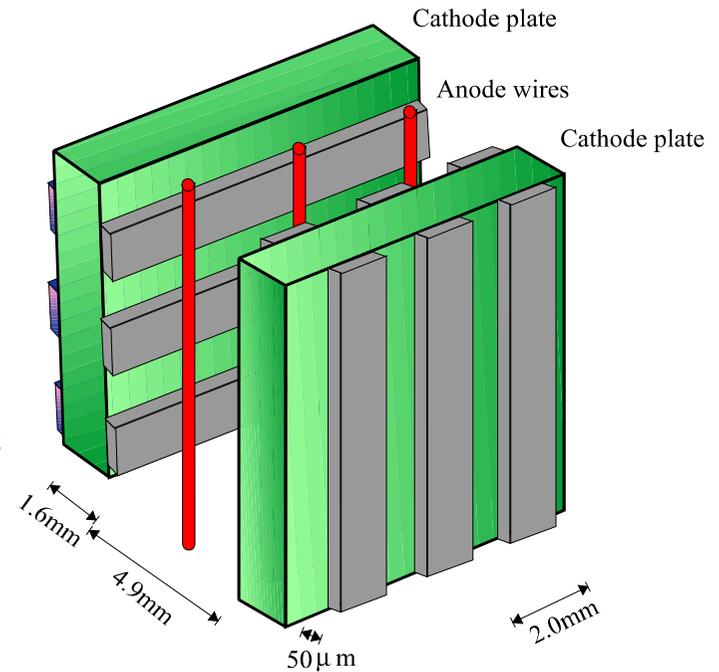
PSD1: Original Birmingham Positron Camera

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

Cathode plate

Anode wires

Cathode plate

•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%

1.6mm

4.9mm

50μm

2.0mm

•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)
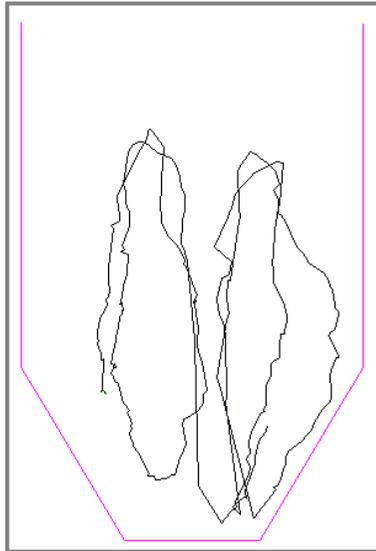
PSD5: "New" Birmingham Positron Camera

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

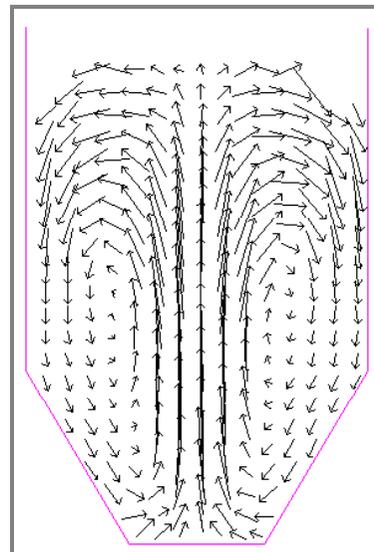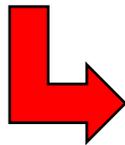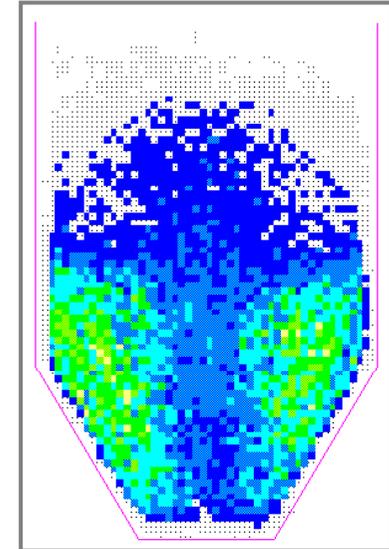Each head contains NaI(Tl) crystal 590x470x16mm^3, 55 PMTs each connected to its own ADC; single board computer

	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

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.

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Examples of standard PEPT

Scraped-surface heat exchanger

Fluidised bed

PSD7: Third generation Birmingham systems
developed from redundant medical PET scanners

Since 2002 PIC has acquired

4 complete PET scanners

and components from two others
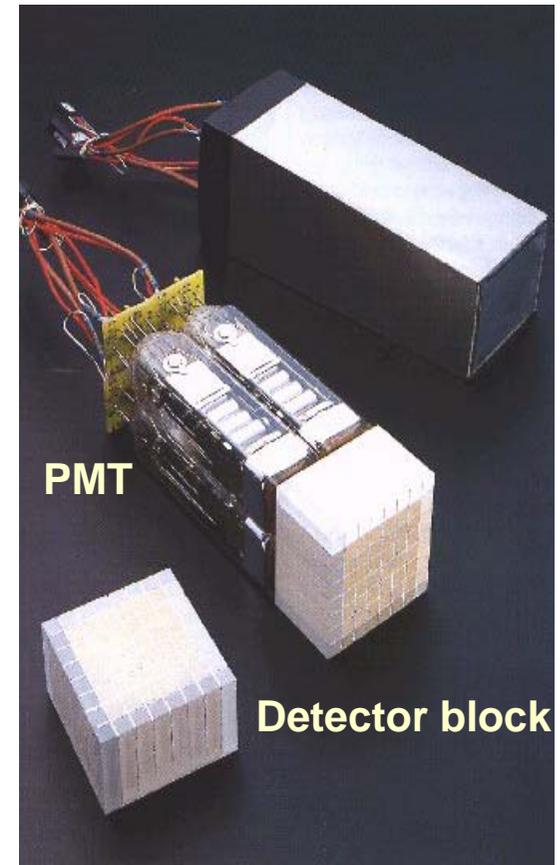

These are inherently modular, and can in principle
be reconfigured in different geometries.

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

They are based on segmented BGO blocks (60x50x30mm^3) cut into 8x4 or 8x8 arrays, and viewed by 4 PMTs

These are grouped in modules ("buckets") comprising 4 blocks plus associated electronics
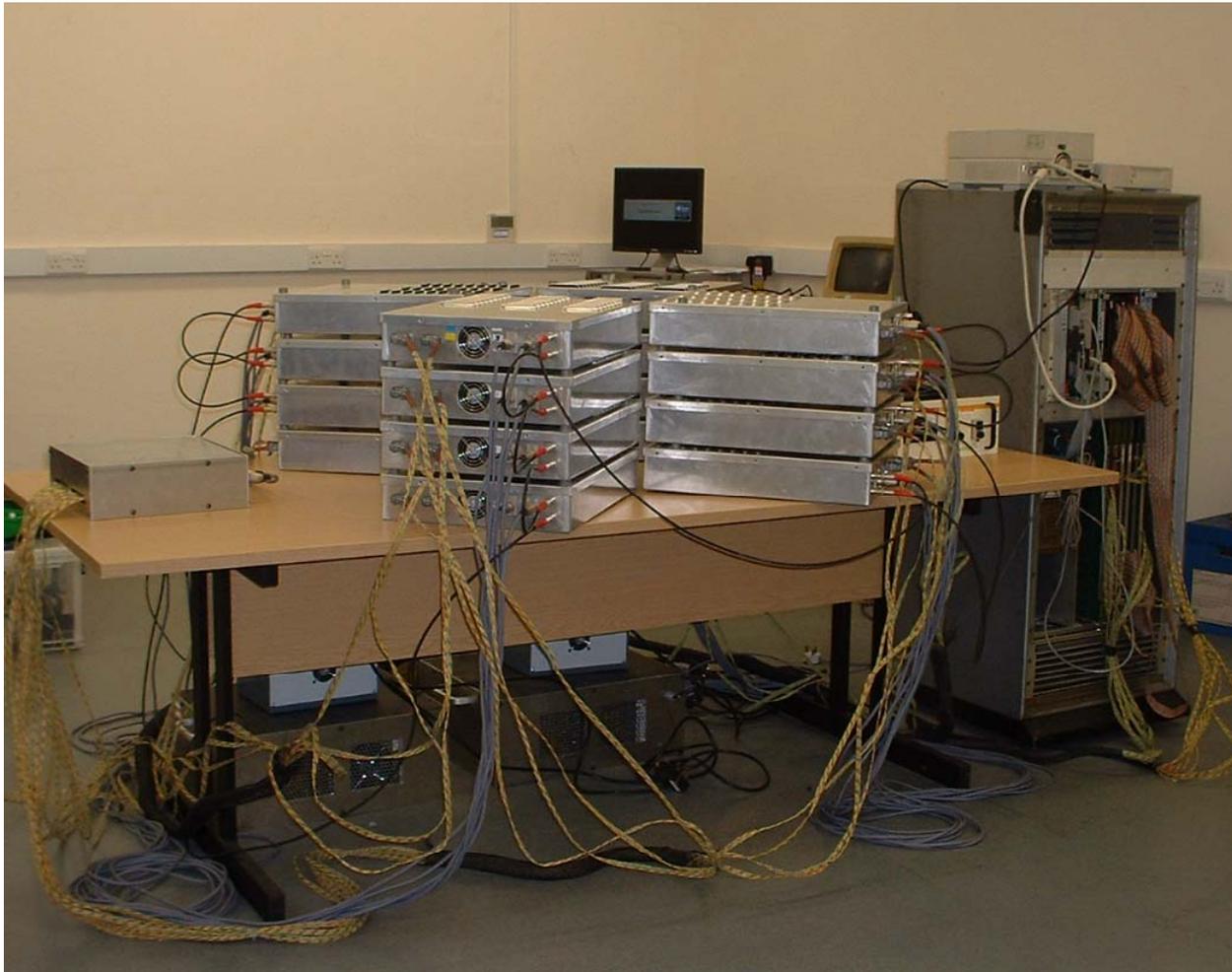

PMT

Detector block

For PEPT, use these modules (in appropriate geometry) and existing coincidence processors, etc
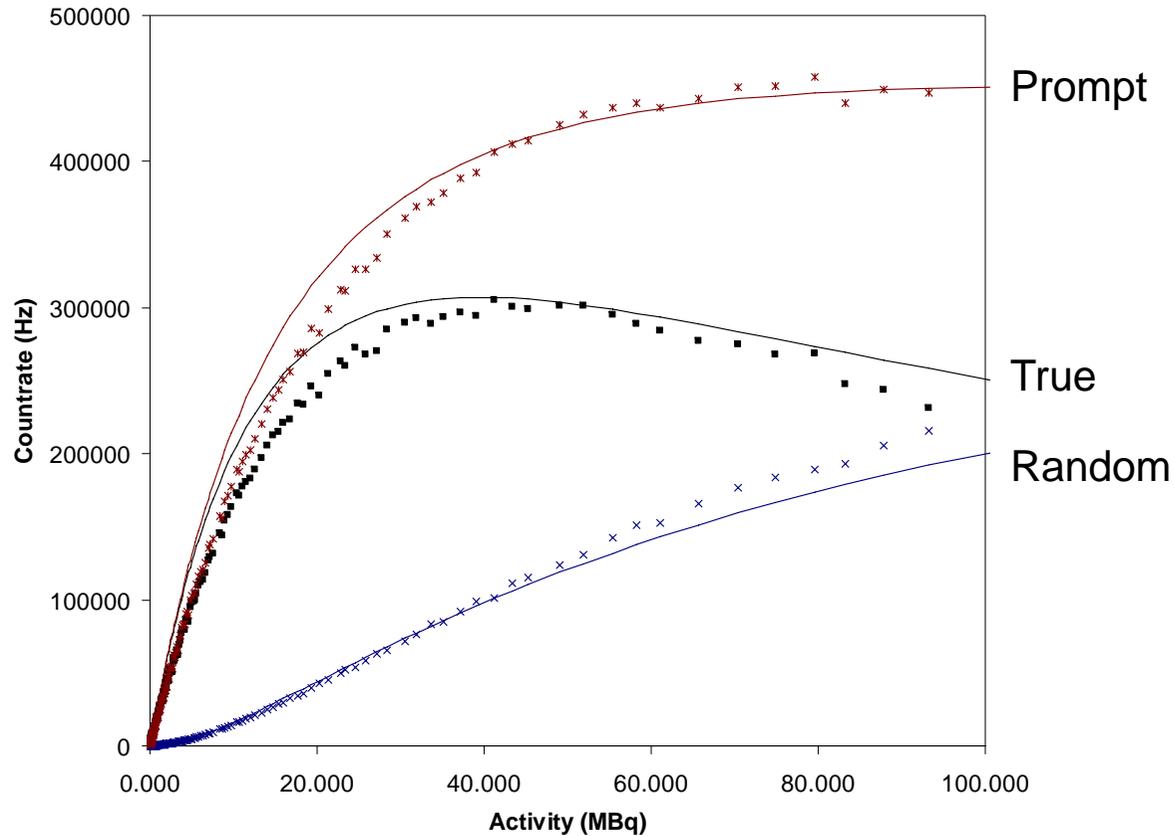
Just need to store data in list mode

Transportable Modular Positron Camera for PEPT

16 detector modules (extendable to 32)

Can be configured in different geometries:
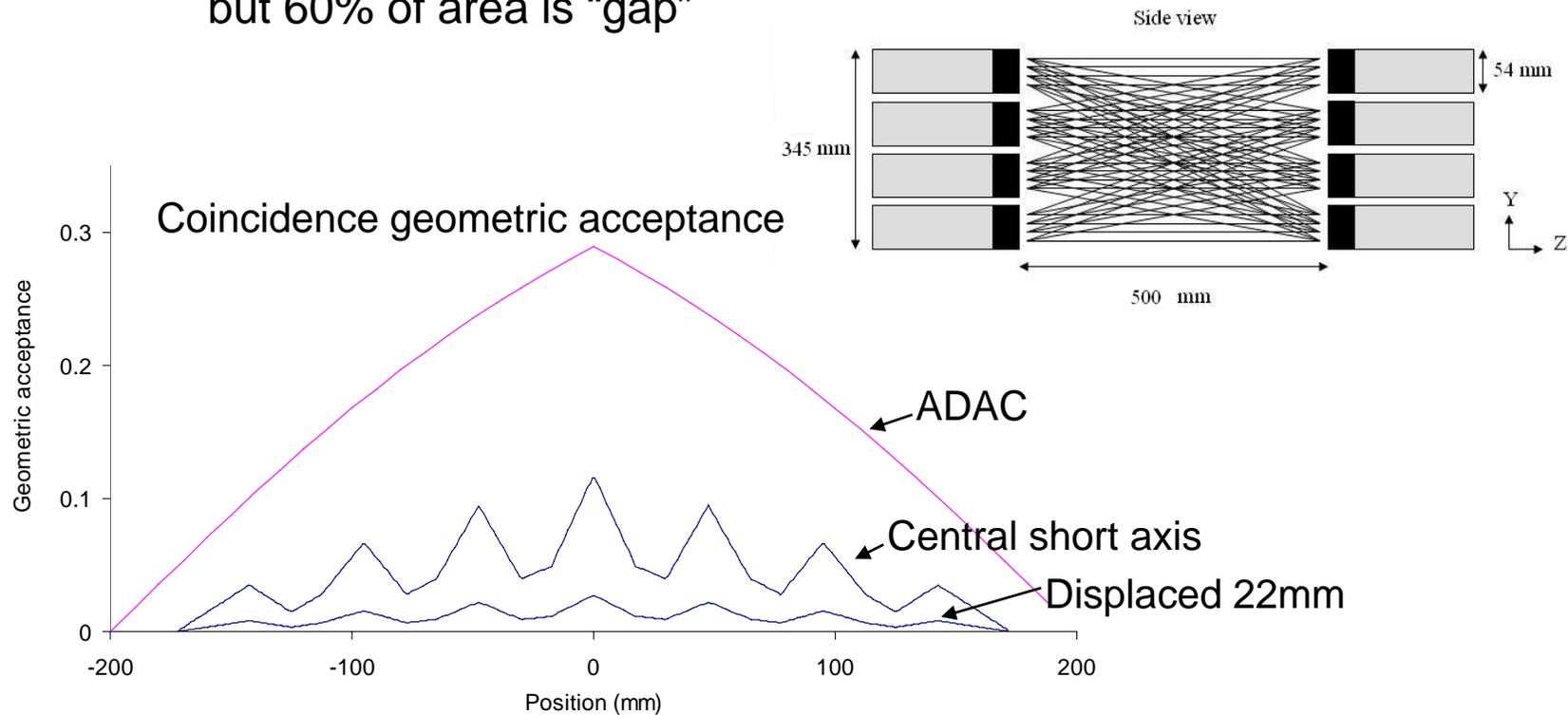
Count rates (close geometry, central source)

Curves are (absolute) predictions of simple model, assuming 0.75μs deadtime in each bucket, and 1μs deadtime in data storage system

 - Latest data acquisition system (T Leadbeater poster) does much better

Effect of gaps on sensitivity

Example: two rectangular arrays, 2 boxes wide x 4 boxes high, separated by 500mm

overall dimensions of each array 666 x 345 mm^2 (comparable to ADAC)

but 60% of area is "gap"

Side view

345 mm   54 mm   500 mm

Coincidence geometric acceptance

ADAC

Central short axis

Displaced 22mm

Geometric acceptance

Position (mm)

0.3
0.2
0.1
0

-200   -100   0   100   200

Gaps have drastic effect on coincidence sensitivity
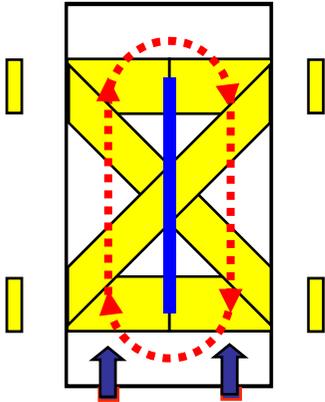
But quantum efficiency of 30mm BGO is ~3x higher than 16mm NaI(Tl)

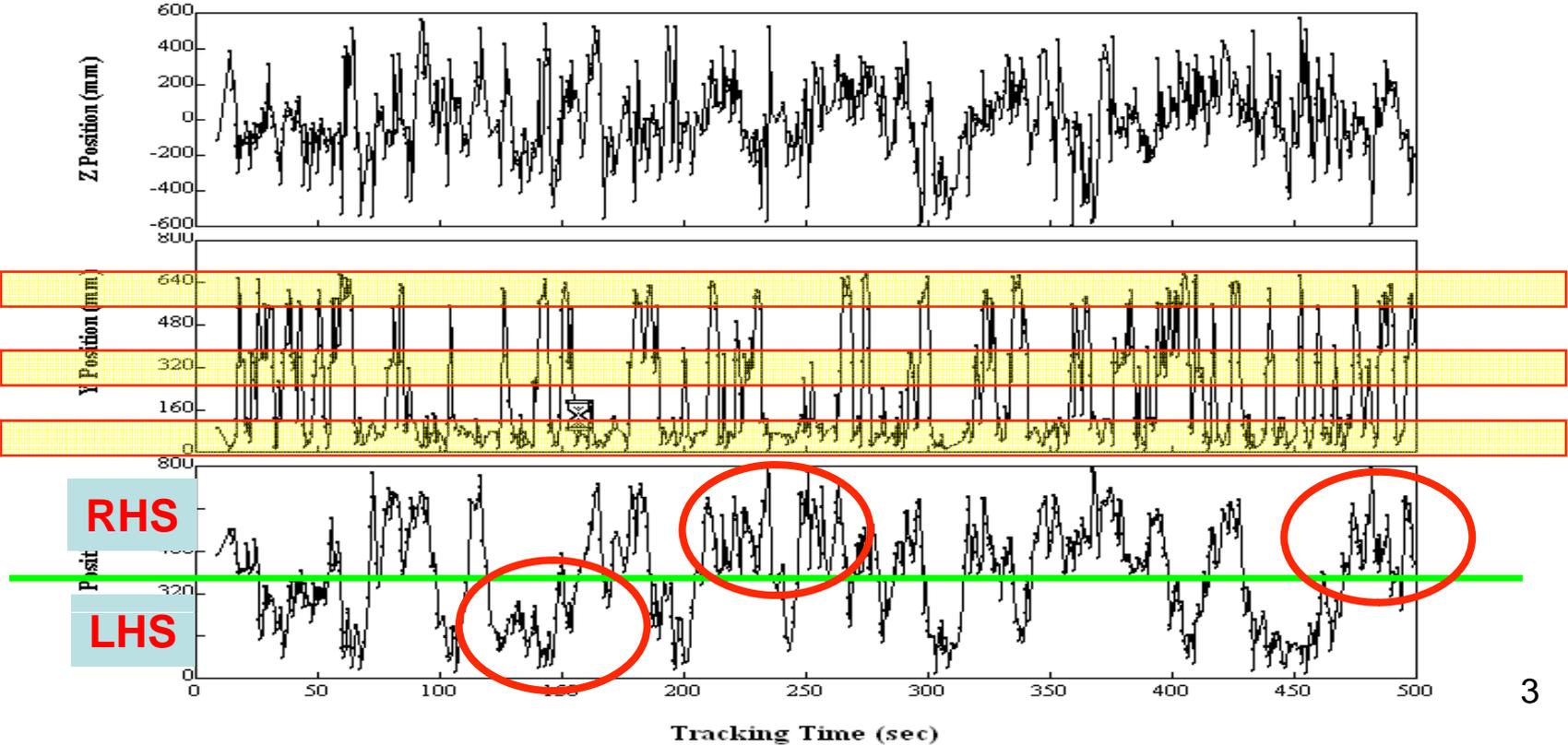So overall, average sensitivity of modular camera is still higher

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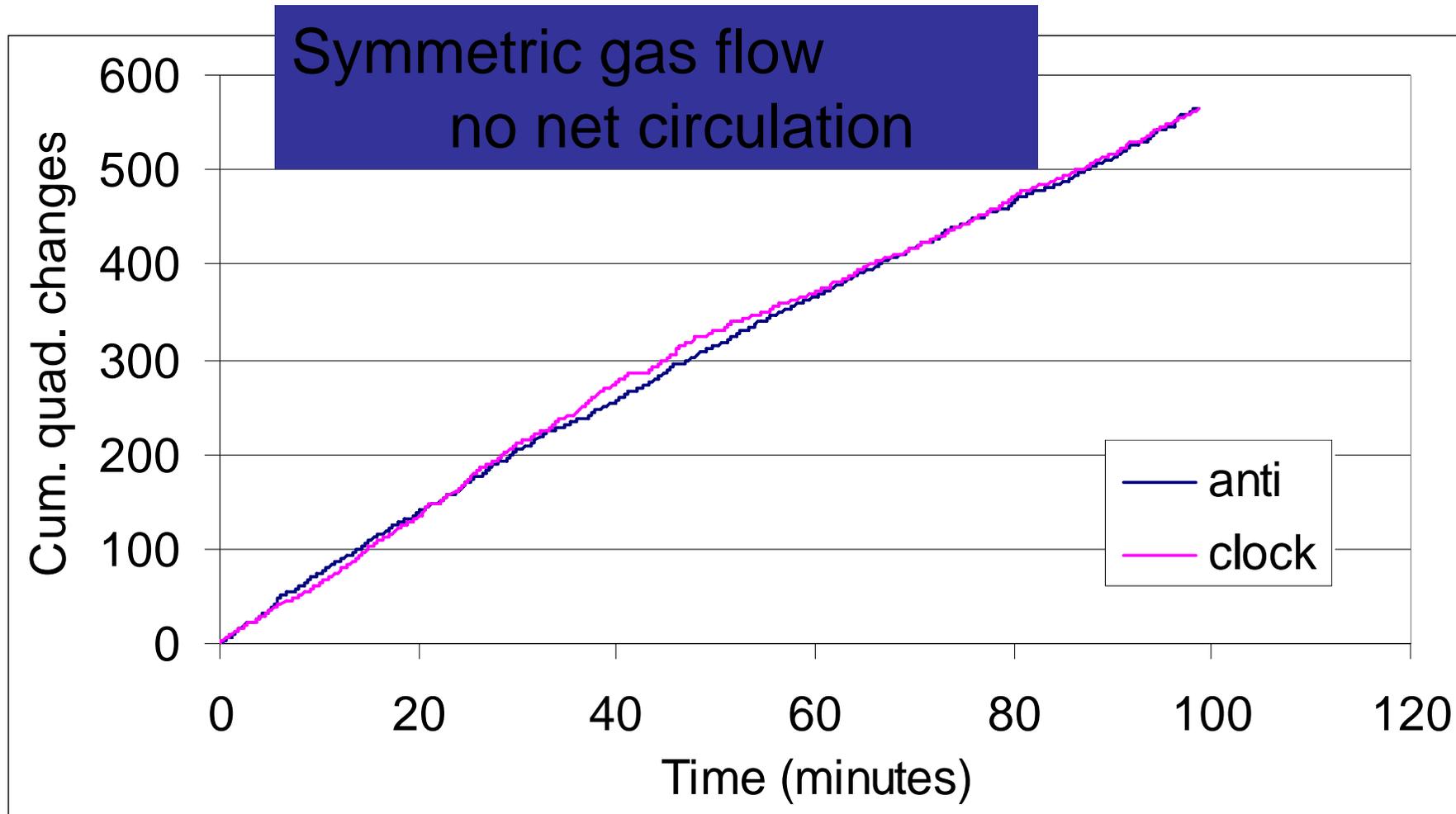# On-plant PEPT study : BP, Hull

(240km from Birmingham)

750mm diameter fluidised bed, with central dividing baffle + different air supplies each side of baffle
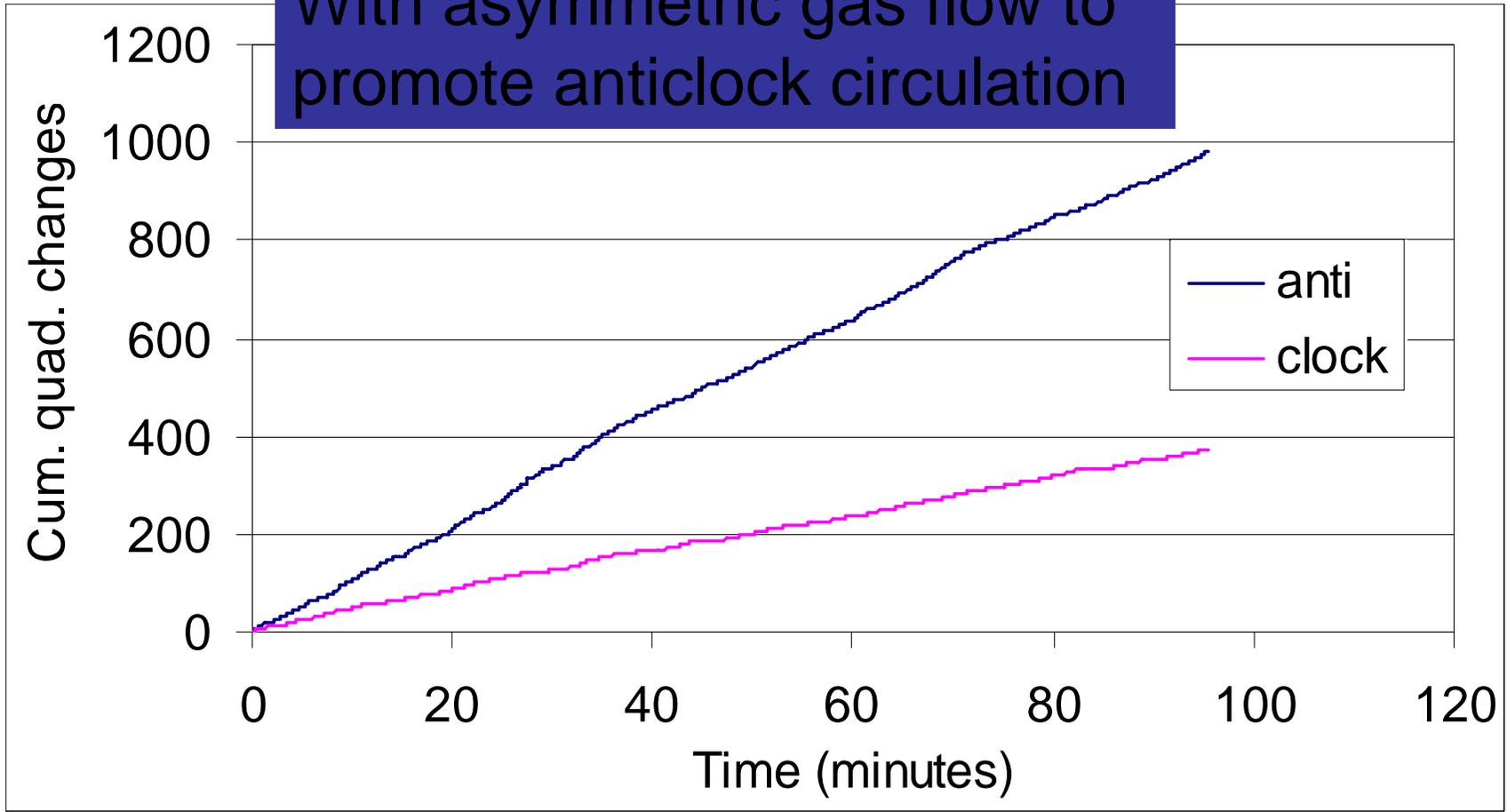
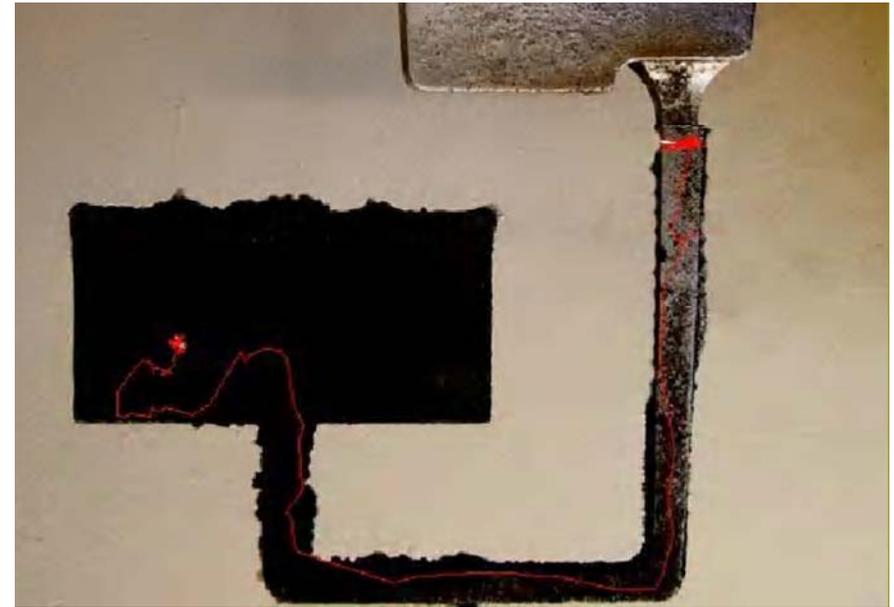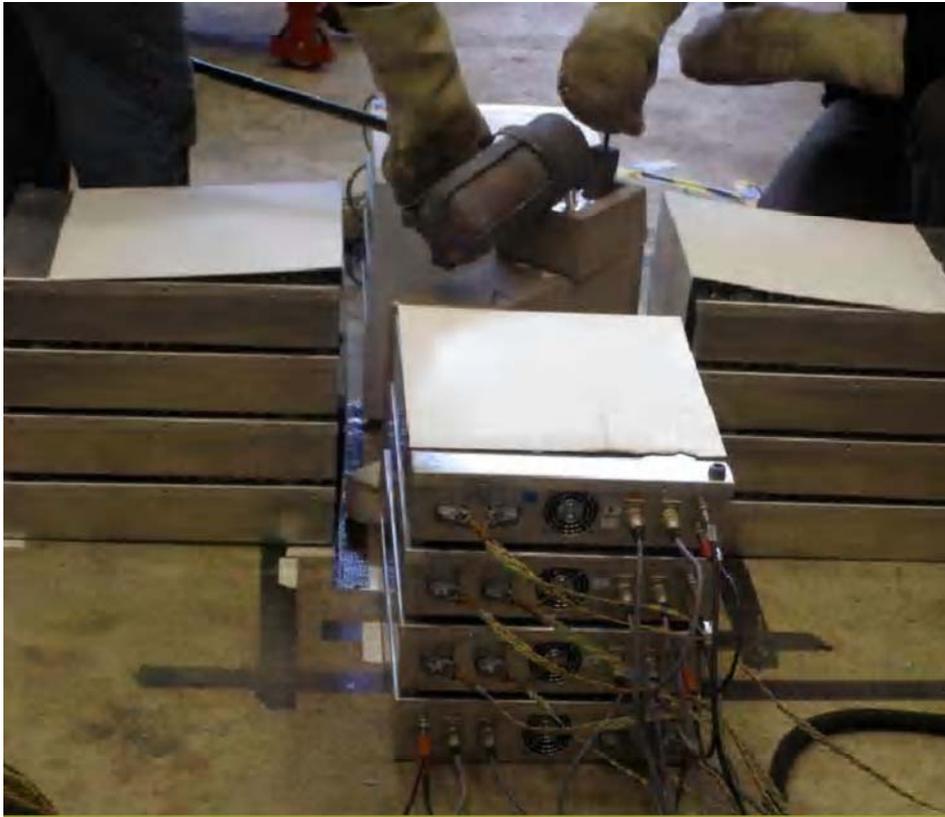4 banks of detectors (detector separation 1.2m) give FOV show

Analysis in terms of movement between four quadrants

Symmetric gas flow
no net circulation

Cum. quad. changes

600
500
400
300
200
100
0

anti
clock

0   20   40   60   80   100   120

Time (minutes)

With asymmetric gas flow to promote anticlock circulation

Casting of liquid aluminium:
PEPT tracking of small alumina inclusion

Summary

Modular camera enables PEPT studies on large systems and outside the lab

Gaps between blocks seriously reduce sensitivity

Count rate was limited by data storage

  – improved system (Leadbeater) gives >1 M s^{-1}

Acknowledgements