# BEAM DIAGNOSTICS AT ISIS

S J Payne, P G Barnes, G M Cross, A H Kershaw, N Leach, A Pertica, S Whitehead, D Wright,
Rutherford Appleton Laboratory, Oxfordshire, UK.

### *Abstract*

ISIS is the spallation neutron source based at the Rutherford Appleton Laboratory in the UK. There are currently 227 individual diagnostic devices distributed between the 70Mev Linac, the 800MeV accelerator ring and the two target beam lines (TS1, TS2). This paper summaries the current development of some of the ISIS diagnostic systems, namely the beam loss monitors, the transverse beam profile monitors and the new electron cloud detectors. The limitations and accuracy of the various diagnostic systems are discussed along with the steps that are being carried out to tackle any shortcomings. This paper will also look at the new PXI based data acquisition and control electronics used by the diagnostic system on ISIS and the problems encountered in using these systems within radiation environments

## INTRODUCTION

Part of the diagnostic development work carried out at ISIS over the last few years has centred on beam loss detection. Damage to components in the accelerator ring has prompted the development of an additional scintillator based beam loss system to complement the argon gas ionisation tubes used at ISIS. The new system, which offers better spatial resolution and sensitivity, is now used alongside the original beam loss system, and is discussed here.

The drive to understand more about the space change effects on the accelerated proton beam, for example, as well as beam injection studies and beam stability measurements has prompted the development of new gas ionisation profile monitor [1] which is also discussed in this paper.

New faster and more sophisticated diagnostics require the use of state of the art electronics especially where many signal channels and fast digitizing are required. At ISIS, PC based PXI systems [2] are being increasingly employed. These new computer systems provide the required level of performance but locating the systems has become a major issue. Shielded areas at the centre of the ISIS synchrotron that were designed to house the original diagnostic electronics (C1984 and mostly discrete components) are proving unsuitable for the high density and miniaturised electronics now being employed. The main problem is poor reliability which could be a result of radiation damage.

Work on new electron cloud detectors is also reported. At ISIS there are currently no known electron cloud instability problems. However, with the drive towards more powerful machines electron cloud effects may be an issue in the future. By building the detectors now expertise in this area can be gained and these new detectors may even show up previously undetected electron cloud issues.

## BEAM LOSS SYSTEMS

### *Background*

The ISIS beam loss monitors (BLM) system consists of around 70 argon gas ionisation tubes housed inside grey steel boxes (see Figure 1) and positioned ~2m from the beam pipe. These BLMs are distributed between the Linac, the two target beam lines and the 70-800Mev accelerator ring. The 39 BLMs used in the accelerator ring are each 3m long and are placed around the inside of the beam pipe. In the Linac and the two beam lines to target, 4m long versions are used. A description of the ISIS BLM system can be found in ref [3].

For the purpose of normal machine tuning and running the BLM system provides good data on the losses around the synchrotron and provides fast tripping of the beam when preset beam loss intensity levels are exceeded.

**Figure 1: A 3m long argon gas beam loss monitor situated in the ISIS accelerator ring.**

Even with the beam loss systems operating normally, problems have occurred in the accelerator ring. Figure 2 shows a circular hole (~26mm diameter) that was punched into an RF shield in one of the 10 dipoles (Dipole 2) in the accelerator ring. It is suspected that this problem is connected with scattering from the suite of collectors (halo scrapers) that are positioned just upstream from Dipole 2. The combination of a coarse spatial resolution (3m long tubes), high radiation background near the entrance of dipole 2, making detection harder, and the BLM positioning from the beam pipe could be responsible for this failure.

With the commissioning of the new second harmonic RF system the ISIS beam current is set to increase from a design maximum of 200uA to 300uA. This proposed increase in beam current means that the protection of such components like dipole 2 becomes even more critical. To tackle current and future beam loss problems a new scintillator based diagnostic has been constructed to complement the existing BLM system. The new system was primarily designed to protect dipole 2 but other applications will most likely follow.

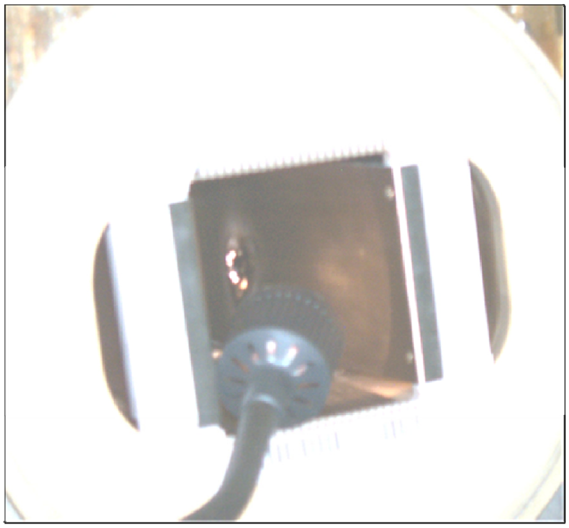


**Figure 2: 26mm hole (centre of picture) in RF shield of accelerator dipole (Dipole 2 of 10).**

## *Scintillator Systems*

The new beam loss diagnostic consists of an array of 12 plastic scintillators (each measuring 150 x 100 x 3mm thick) positioned along the inside radius of the ceramic vacuum vessel of Dipole 2 [4]. Figure 3 shows three such scintillators being mounted onto a glass fibre board. Also shown (insert in figure) is one of the 12 photomultipliers used and the DAQ system which is a PXI system from National Instruments [2].

The scintillator material used is BC408 [5] which is a general purpose organic scintillator sensitive to most types of radiation (neutron, gamma, x-ray etc.). Each scintillator is connected to a photomultiplier tube using 20 polymer optical fibres, where each fibre is set into one of 20 holes along one short side of the scintillator (Figure 4 shows construction details). The scintillators and photo-multiplier tubes are first calibrated against each other using a strontium 90 source. After calibration the scintillators are mounted onto fibre boards and then inserted into the dipole between the ceramic vacuum vessel and the outer casing of the dipole as shown in Figure 5.

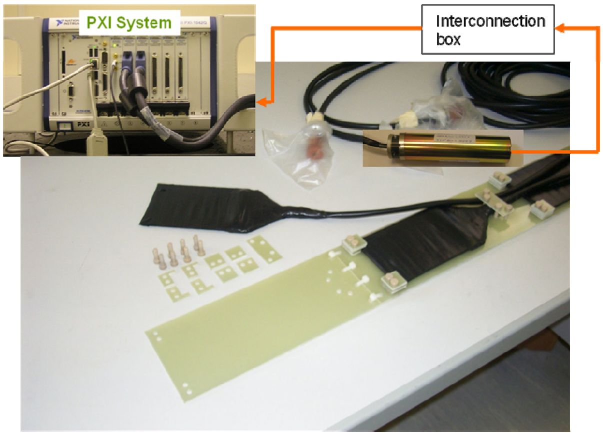


**Figure 3: scintillator layout on fibre board showing (insert) a photomultiplier tube and the PXI based DAQ system.**

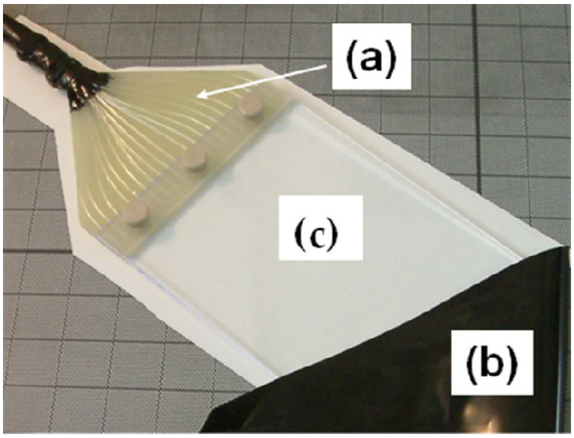


**Figure 4: Scintillator Construction. (a) 20 polymer optic fibres (b) light proof reflective covering, (c) BC408 plastic scintillator (size 150 x 100 x 3mm).**

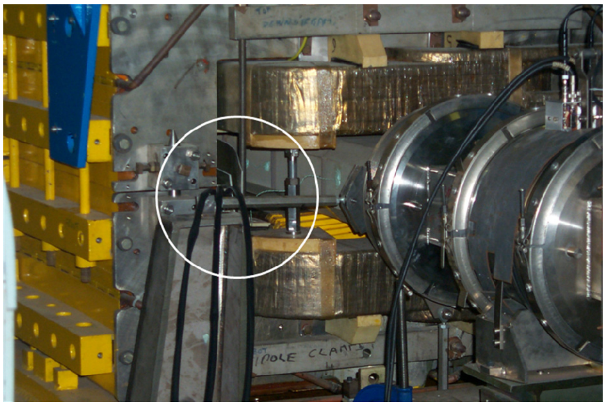


**Figure 5: Scintillators inside Dipole 2.**

Figure 6 shows losses recorded by three of the new scintillators located at the upstream end of dipole 2.

The losses at 4ms in the acceleration cycle cannot be seen by either argon gas BLM's or indeed by the (toroid) intensity monitors. This result highlights the increased sensitivity of the scintillator system which allows it to be used in an ‘early warning’ role during high intensity set up.

Figure 7 shows a PXI screen shot of the 12 scintillators along the dipole. The graphic in the centre of the panel indicates the position of the 12 scintillators within dipole 2. In the figure shown these are coloured red but would normally be white. The idea is once the beam loss data is saved then any changes in the integrated beam loss over a predetermined percentage level will light the scintillator square red thus forming a visual representation of where the loss is occurring. The PXI display window also allows scintillator traces from different scintillators to be superimposed.

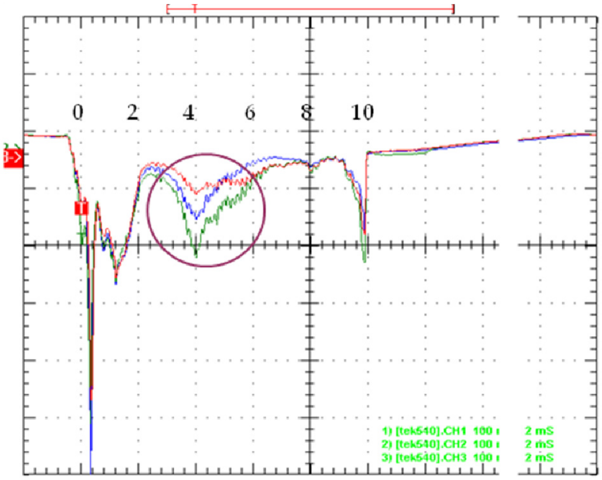


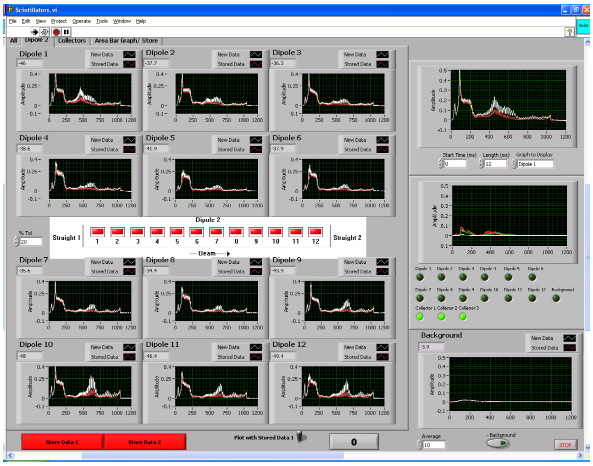
**Figure 6: The loss seen by 3 of the new scintillators at ~4ms during the 10ms ISIS acceleration cycle. This loss was not detectable on the argon BLM’s or the toroid intensity monitors.**

## PXI DATA ACQUSITION

The original data acquisition system used at ISIS was a ‘machine code’ programmed microcomputer fitted with a Motorola 6800 processor and 1K of onboard memory. These micros are quickly being phased out and are being replaced with PC based PXI systems. The PXI systems offer a large range of data acquisition and control cards and are compact so they can easily be fitted into existing equipment racks.

In general, the PXI DAQ systems work extremely well. However there have been many (possibly radiation induced) reliability issues surrounding these systems.

The PXI’s are located at the centre of the synchrotron (see Figure 8). This area is shielded from the accelerator ring by a wall of concrete blocks 2m thick. Following installation into this inner area all the PXI systems have followed the same failure path where the first symptom has been the locking up of the LabView programs. The cure was to simply stop and restart the program. However within days, even hours in some cases, the PXIs would crash and had to be rebooted. This required switching off and on the power to the PXI crates as all control to the PXI had been lost. The final stage occurred, when the PXI could not be rebooted. Investigation showed that the hard drives of these PXI systems had been severely damaged by the read heads hitting the disk surface and effectively destroying the drive.



Dipole 1 -46
Dipole 2 -37.7
Dipole 3 -36.3
Dipole 4 -38.6
Dipole 5 -41.9
Dipole 6 -37.9
Dipole 7 -35.6
Dipole 8 -34.4
Dipole 9 -43.9
Dipole 10 -48
Dipole 11 -46.4
Dipole 12 -49.4
Background -3.9
% Tol 20
Start Time (ms) 0
Length (ms) 12
Graph to Display Dipole 1
Average 10

**Figure 7. Screen shot of PXI system showing the output of the 12 scintillators located along the length of dipole 2. Red trace is stored data, white is live data.**

Talks with National Instruments produced two solutions. The first was to replace the hard drives with a ‘ruggedized’ version. The original Fugitsu hard drive was replaced with a Seagate drive of a type used in the automotive industry. The second solution was to remove the controller (and hence the hard drive – Figure 9) from the PXI chassis and move the controller to a safe area, in this case the diagnostics room which is an annex of the main synchrotron control room. Here a second PXI chassis was employed to run the controller and a MX-4 opto-coupler control card that enables communication between the controller and the PXI crate located in the synchrotron inner.

Both these solutions have met with a good degree of success. The only system currently using the MX-4 fibre optic link has not failed to date. The PXI systems that still are located in the synchrotron inner (and now have the new Seagate drive fitted) have been almost 100% reliable with just two having had the first symptom of the LabView program crashing. Whether this is just the start of troubles with the new drive is unknown at this stage.

The culprit for the PXI demise could be radiation but this is still to be proven. Although the PXI systems are in a ‘shielded area’ there is concern that strikes from high energy neutrons and secondary charged particles are causing the damage. It should be noted that no problems have been reported on PXI systems situated outside the inner synchrotron area. The situation in the synchrotron inner is being monitored closely.

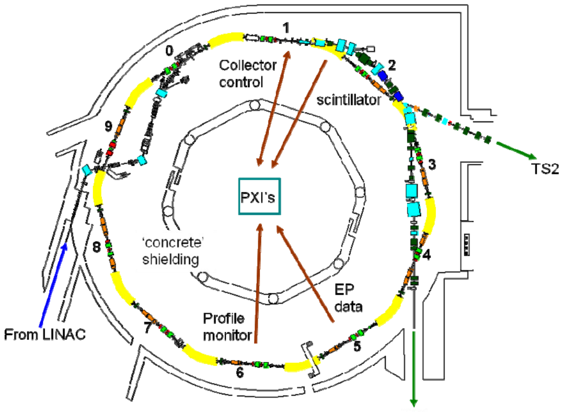


**Figure 8: Accelerator Ring layout illustrating PXI position with the shielded area and the centre of the synchrotron. Some systems using the PXIs are mentioned.**

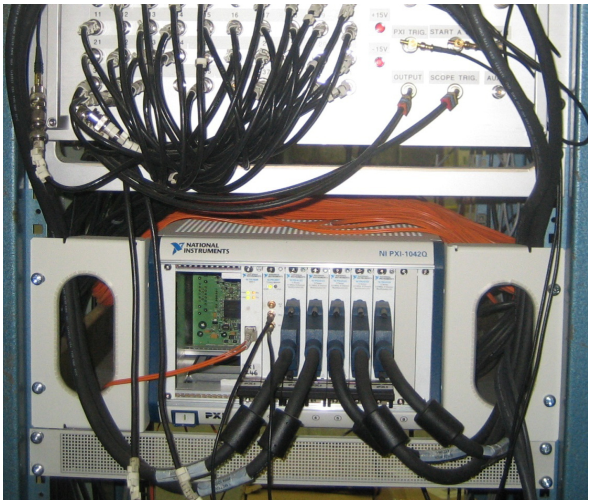


**Figure 9. A PXI system located within synchrotron inner. The controller has been removed to a 'safe area' (the ISIS diagnostics room) and is linked to the crate using a MX-4 fibre optic cable (orange in photograph).**

## BEAM PROFILE MONITORING

### *Background*

The ISIS accelerator ring employs 5 residual gas beam profile monitors; three measure the profile in the horizontal plane and two in the vertical plane. These monitors consist of a single electron multiplier (Channeltron) which is stepped across the beam in 5 or 10mm increments. The channeltron amplifies the +ion current (~200pA at centre of beam) produced by the interaction of the proton beam with the residual gas in the beam pipe. Figure 10 shows a photograph of a horizontal profile monitor and a sketch highlighting the basic principles. The process of collecting a profile takes about 3 minutes to complete and therefore real time studies of the beam are not possible. However such beam studies are essential not only to get the best performance out of the current synchrotron but in order to do detailed machine studies (space charge effects, beam injection, beam instabilities), the results of which will be critical the development for future higher intensity machines [6].

The solution to the problem was to build a profile monitor that used an array of 40 channeltrons spanning 240mm across the top of the beam (Figure 11). The data from this array is collected using a PXI data acquisition system which employs 5 x 8 channel DAQ cards that are simultaneously sampled. The new profile monitor is located in the same vacuum vessel as the original mechanical device (see Figure 12) and uses a second set of drift field electrodes, (used to produce a compensating field), to collect the +ions.

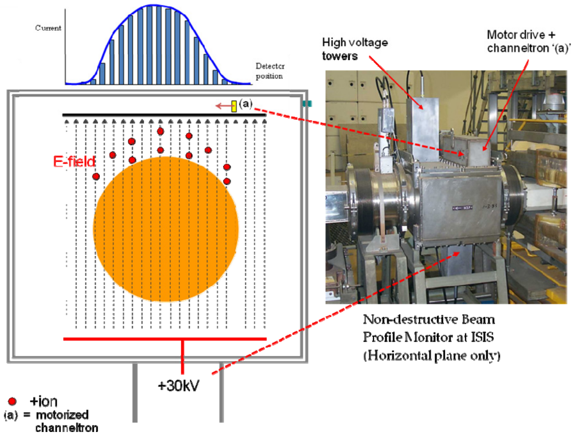


**Figure 10: ISIS gas ionisation profile monitor. A +ion detector [(a) in figure] is stepped across the beam to construct the beam profile.**

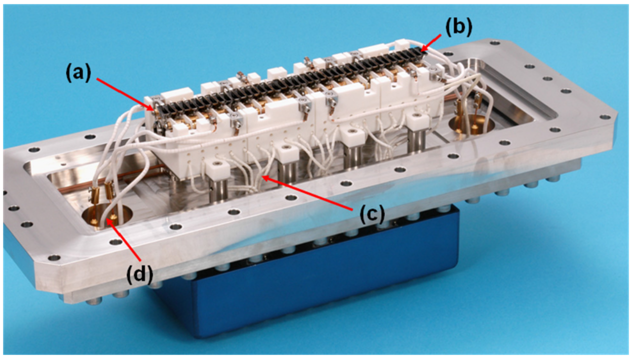


**Figure 11: The new ISIS multi-channeltron beam profile monitor. (a) is channeltron 1 (b) is number 40. (c) are the channeltron output wires and (d) the high voltage bias (-1300V) and power supply return connections.**

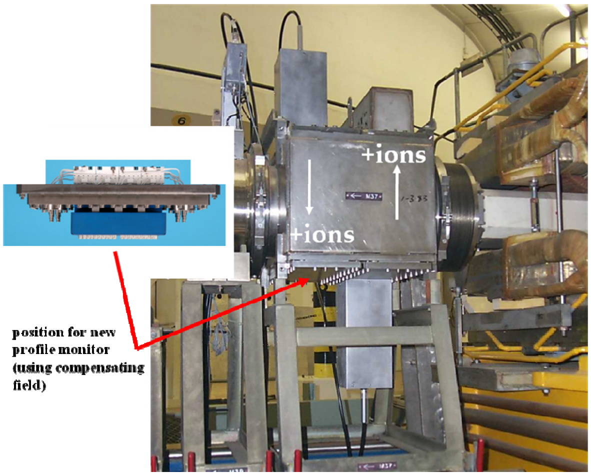
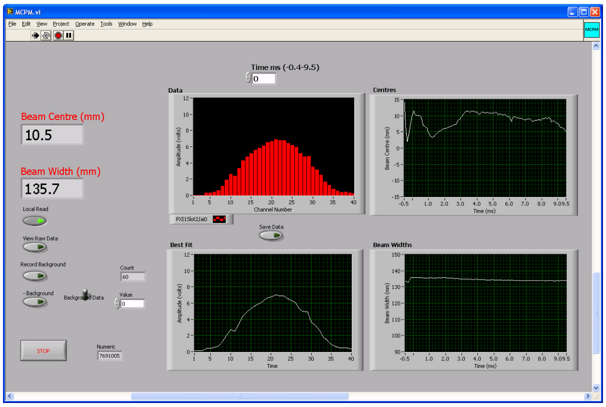


**Figure 12: position of new profile monitor using compensating electric field. The ions would normally just strike a blanking plate.**

Figure 13 shows a LabView from panel of the data collected from the first (horizontal) monitor that was installed into ISIS.



Time ms (-0.4-9.5): 0

Beam Centre (mm): 10.5

Beam Width (mm): 135.7

Count: 60

Value: 0

Numeric: 7691005

**Figure 13: Output of multi channel profile monitor / PXI DAQ system using LabView program.**

## *Detector calibration*

The raw data seen from the 40 channeltron array is not good enough to be used to extract profile information. The roughness of the data is due to the differing gain between the individual channeltrons which can be a factor of 2 of 3 different. To overcome this problem the single channeltron is moved across the beam such that it precisely lines up with each one of the 40 detectors in the multi-detector array. At each step data is taken by both the single channel detector and the corresponding channeltron in the detector array and this is used to produce a calibration file. Once this file has been obtained then the output from the new detector is processed using the calibration data.

## *Beam Profile errors*

The measured profile from this type of gas ionisation monitor depends largely of the value of the drift field the symmetries in the electric field and space charge effects. Figure 14 shows, for example, the measured beam width as a function of drift field voltage (from 10kV to 30kV in this case) [7]. A lot of effort has been put in recently to understand the effects of space charge and drift field distortions on the measured profile. This work is reported in [8, 9]. Early results show that the effect of both the space charge and the drift field asymmetries can produce measured beam profiles as much as twice the actual width.

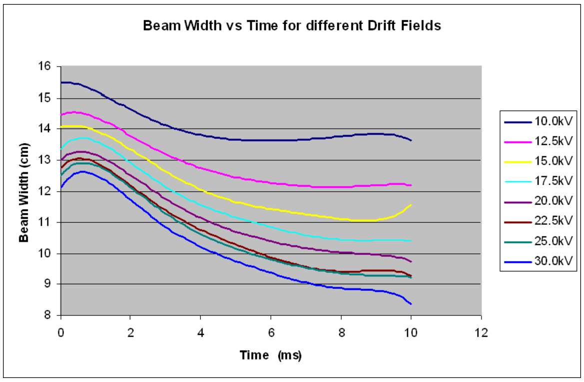


**Figure 14: Plot showing variation of Beam width with changes in bias field.**

# ELECTRON CLOUD

## *Background*

Electron cloud instabilities have been observed in many accelerators worldwide [see for example 10-12]. These instabilities can severely hinder the performance of the accelerator / storage ring and keep beam intensities below the design limit of the machine.

Damage caused by electron clouds include quenching of superconducting cavities due to the heating effect of the electron bunch; damage to ceramic vacuum seals, emittance growth, interference with diagnostics.

At ISIS there has, to date, been no known occurrence of such instability. However with commissioning of the 2nd harmonic system and the proposed mega-watt upgrade plans [13, 14] it was decided to design and build electron cloud detectors to look for signs of EC instabilities.

The design for the EC detector is commonly referred to as a retarding field analyser (RFA). The ISIS RFA is shown in Figure 15. The detector consists of an electron collector plate and an energy analyser grid. Two such RFA's are now installed into ISIS using a modified beam pipe that also houses one of the accelerator ring's ion vacuum pumps. This is shown in Figure 16. The system is now awaiting an amplifier system capable of detecting low current signals (nA. to uA. region) with a 30-50MHz bandwidth. The electronics are now under construction.

It should be noted that initial electron cloud studies were carried out at ISIS using the mechanical profile monitors discussed earlier. The idea was to place the channeltron in the centre of the beam path with the drift field turned off. The channeltron is capable of picking up electrons as well as +ions. To 'encourage' the production an electron cloud the local vacuum pumps were switched off thereby creating higher levels of ionisation electrons. The result of this experiment was inconclusive. No real increase in electron signal could be detected during the acceleration cycle.

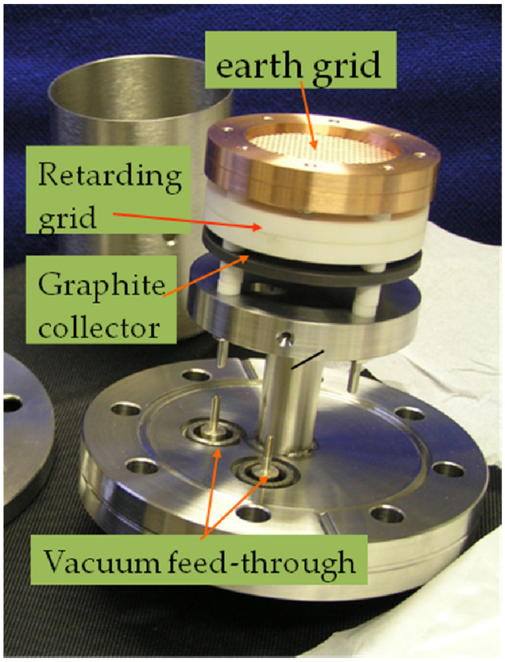


**Figure 15: an (RFA) electron cloud detector installed in the ISIS accelerator ring.**

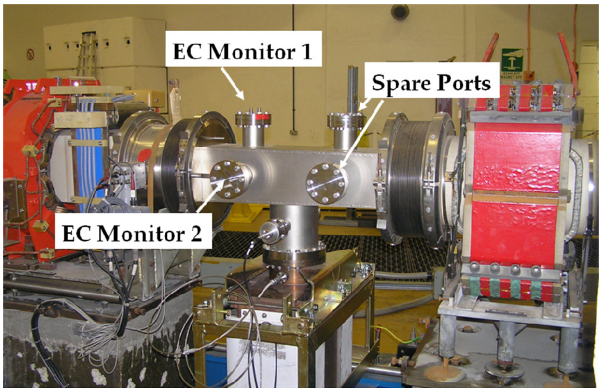


**Figure 16: EC detectors located in accelerator ring.**

## ACKNOWLEDGEMENTS

The authors gratefully acknowledge the essential collaborations with ISIS Accelerator Physics, the ISIS Detector Group and the ISIS Detector Electronics Group.

## REFERENCES

[1] S J Payne, *et al*, "A Self Calibrating Real Time Multi-Channel Profile Monitor for the ISIS Proton Synchrotron", Proc. of DIPAC 2007, Venice, Italy.
[2] For examples of PXI DAQ systems see National Instruments, http://www.ni.com.
[3] M A Clarke-Gayther *et al*, "Global Beam Loss Monitoring Using Long Ionisation Chambers at ISIS." Proc. of EPAC 1994, London, England, UK.
[4] S J Payne, S A Whitehead, "Fine Spatial Beam Loss Monitoring for the ISIS Proton Synchrotron", Proc. of EPAC'06, Edinburgh, UK.
[5] For BC408 details see scintillation-europe@saint-gobain.com
[6] C M Warsop, "Transverse Space Charge Studies for the ISIS Synchrotron", Proc. of EPAC'06, Edinburgh, UK.
[7] S J Payne *et al*, "Investigation into the relationship between the drift field voltage and measured beam width on the ISIS ring profile monitor system", Rutherford Appleton Laboratory ISIS Machine Physics Report, IADM/MPS/2.1/03 (2003).
[8] B G Pine *et al*, "Modelling of Diagnostics for space charge studies on the ISIS Synchrotron", Proc. of EPAC'06, Edinburgh, UK.
[9] R E Williamson *et al*, "Analysis of Measurement Errors in Residual Gas Ionisation Profile Monitors in a High Intensity Proton Beam" Proc. of EPAC'08, Genoa, Italy.
[10] J Q Wang *et al*, "Electron cloud instability studies in the Beijing Electron Positron Collider" Physical Review Special Topics – Accelerator and Beams, Volume 7, 094401, (2004).
[11] W Fischer *et al*, "Electron Clouds and Vacuum Pressure Rise in RHIC" Proc. of ECLOUD'04, Napa, California (2004).
[12] G Arduini *et al*, "Measurement of the Electron Cloud Properties by means of a Multi-Strip Detector in the CERN SPS" Proc. of EPAC 2002, Paris, France
[13] D J S Findlay *et al*, "ISIS Upgrades – A Status Report", Proc. of EPAC'06, Edinburgh, UK.
[14] J W G Thomason *et al*, "Megawatt Upgrades for the ISIS Facility", Proc. of HB2008, Nashville, USA.