# Sensor cooling at the Birmingham Irradiation Facility

## WP8.3.2 Common infrastructure for facilities


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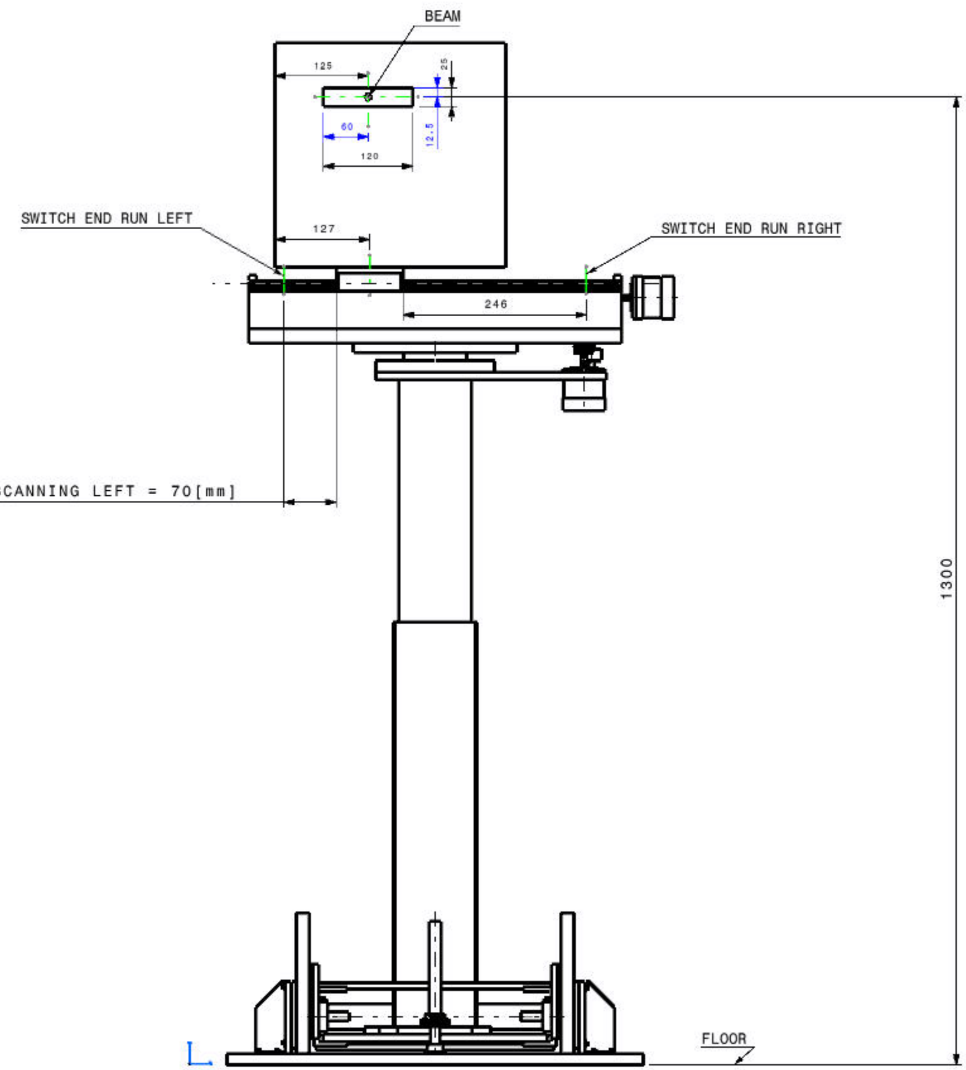

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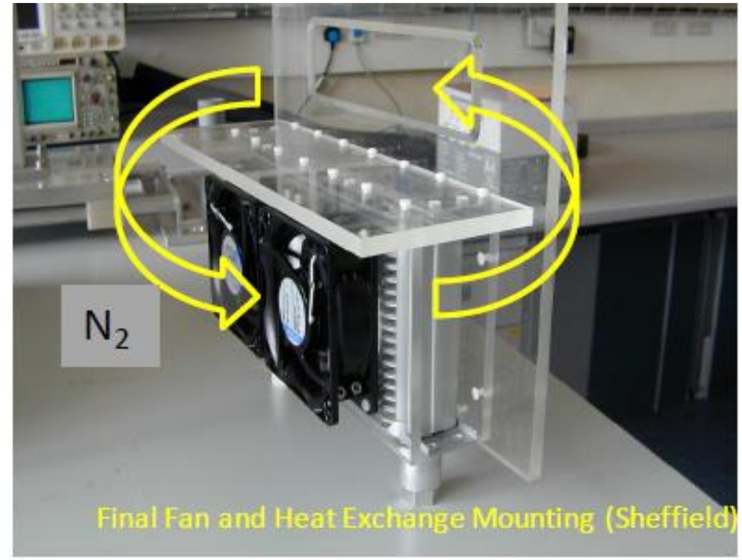
# Evolution: Controlled environment box for irradiation of silicon sensors at CERN PS

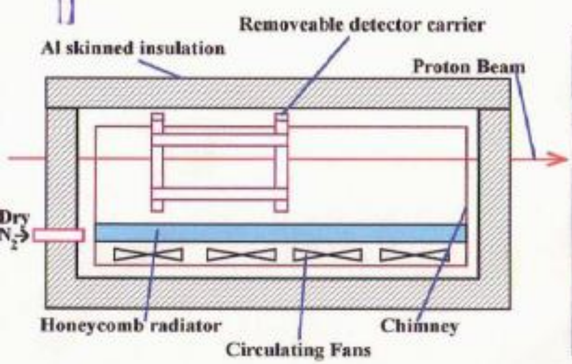
As per similar proven systems used at CERN PS since 1997 (old slide in bottom left): Chilled Nitrogen circulated by AC powered fans through HEX cooled by Glycol circulated by 2xHakke chiller units (1600W) . We use only radiation hard materials and components. Original concept designed by Sheffield, currently producing all parts.

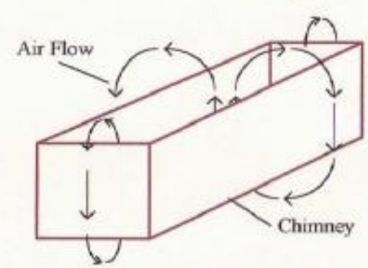



*1997 to present day*

•Detector mounting PCB and bonding underway at Liverpool

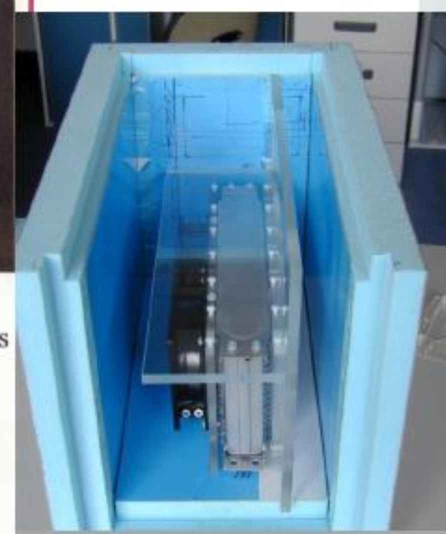
## Controlled environment box




**The chimney improves air circulation**

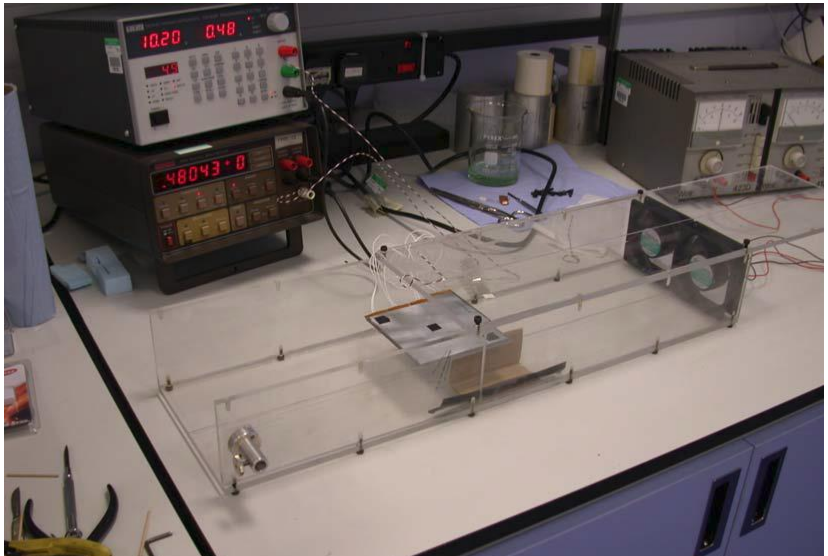
- Keeping the detectors at a constant temperature during irradiation is vital since radiation damage is temperature dependent.
- Many other cooling ideas for use at LEP were found to be unacceptable on safety grounds, or have failed to regulate.
- The chosen system maintained a 2 degrees celsius temperature gradient across the box throughout the irradiation.



Fan + HEX in test thermal box

Richard French

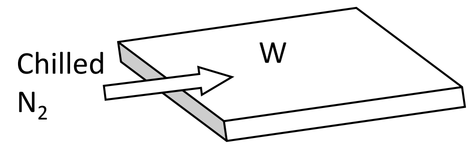
# Proving the forced convection cooling

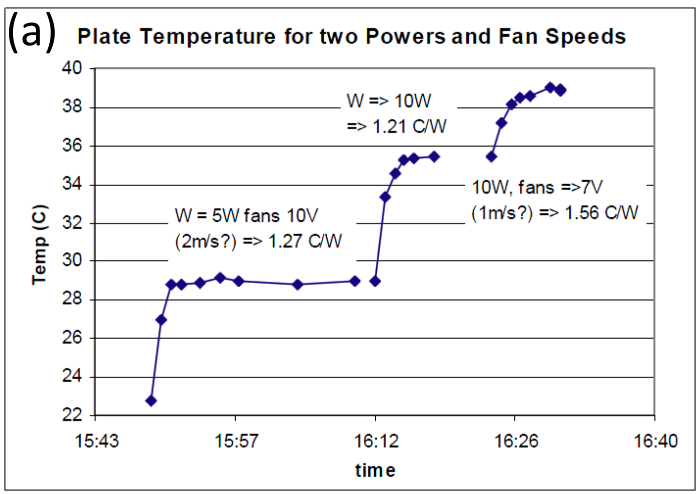



Test system built at QMUL to prove concept

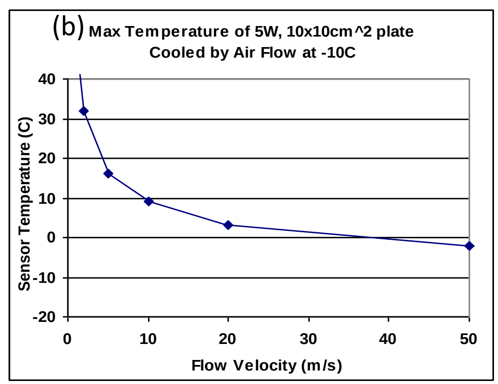
•Air (here at room temperature) is blown through a perspex duct by two 8x8 $cm_2$ fans.
•The cooled structure is a 10x10 $cm_2$ sandwich of two 0.6mm Al plates, enclosing kapton film elements providing uniform heating.
•Airflow speed (judged from injecting small fragments of Kleenex) is of order 1m/s. The lid of the duct is displaced to allow measurement of the surface temperature by a spot radiometer (3xblack squares).
•FYI: the DC fans are nominally 12V, 2W each. Note that the rise in air temperature is not measured. Production box uses higher powered AC fans.
•In general this can be estimated from: $\Delta T(gas) = W/(v.A.\rho.Cv)$.
As an example, choosing some appropriate round numbers:
W=1Watt, v = 1 m/s, A = 20cm x 5cm = 10-2 m2. ρ (NTP) = 1.2 kg/m3, Cv ~ 1 kJ/kg/K
=> ΔT(gas) ~ 0.8C, low enough (for such conditions) that the exit gas should be re-used (rather than vented).

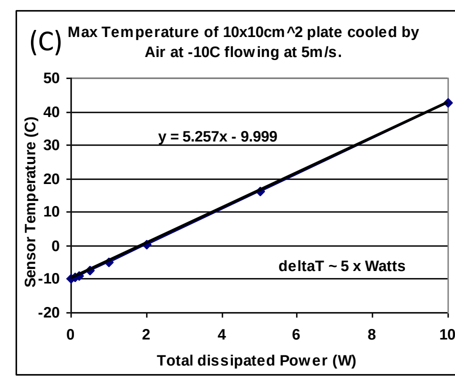
Assume that nitrogen is pre-cooled and blown across the detector surface (with detectors edge-on to the beam (a)




The plots below are calculated (following a worked example from Holman [1]) for the cooling of a Flat Plate dissipating a constant heat flux by air flowing across it at a given speed and temperature.



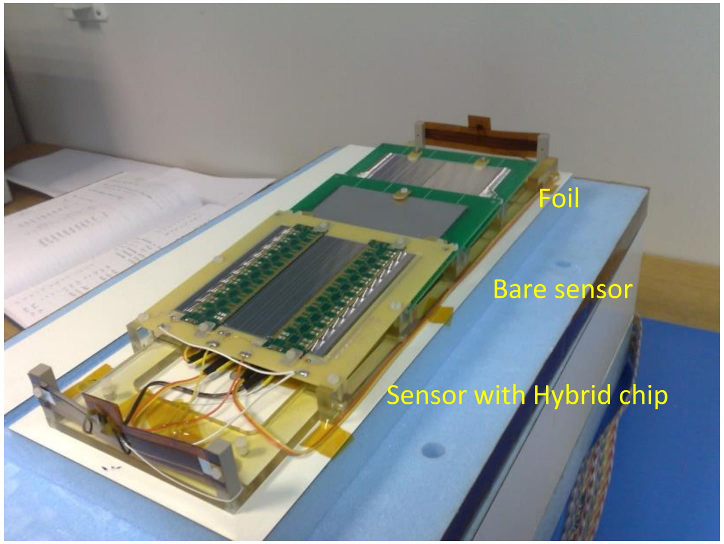


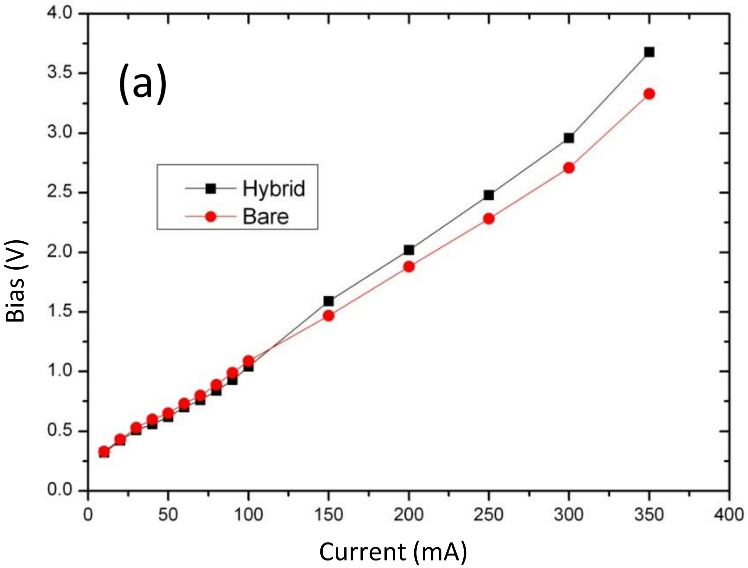
[1] Heat Transfer, J.P.Holman, 8th edition, p 244.


A change in air temperature produces a similar shift in sensor temperature. However, there is a strong velocity dependence (b). The power dependence (c) is essentially linear.


Graham Beck

# 1st PS Sensor Irradiation



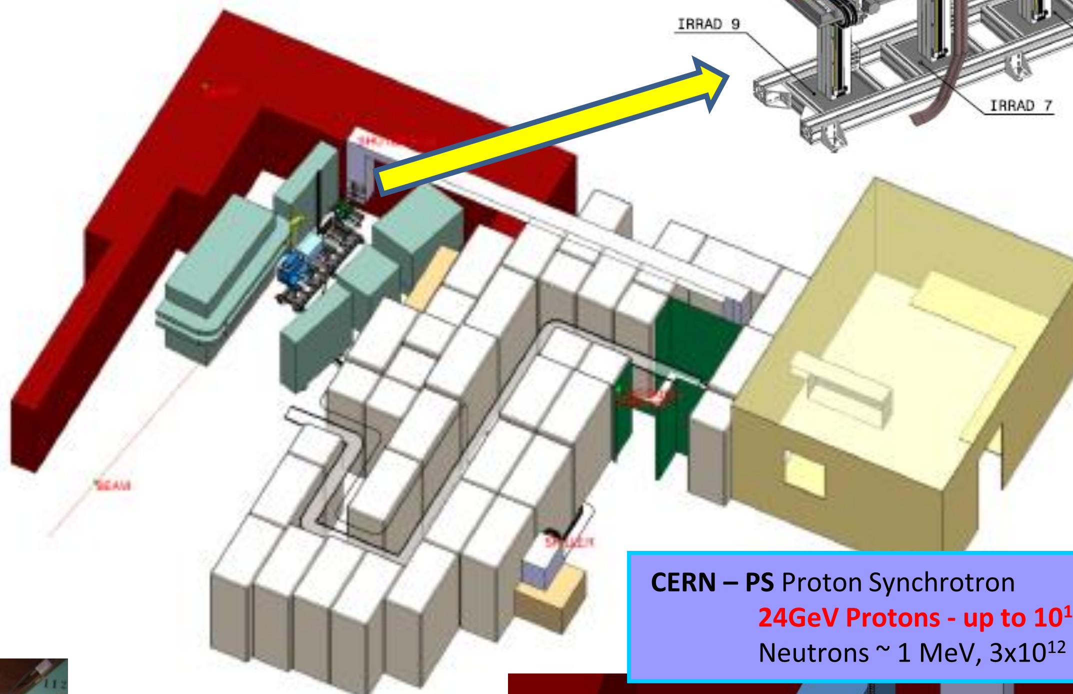

- One bare sensor and one sensor with hybrid glued on it – can the glue damage the sensor?
- Irradiated to $1.82 \times 10^{15}$ p/cm$^2$ in the cold box on the CERN PS IRRAD scanning table
- Reverse current at the end of irradiation (a) (black with bare sensor, red with hybrid).
- Temperature on chiller at -16$^o$C
- No degradation due to gluing of the hybrid onto the sensor.

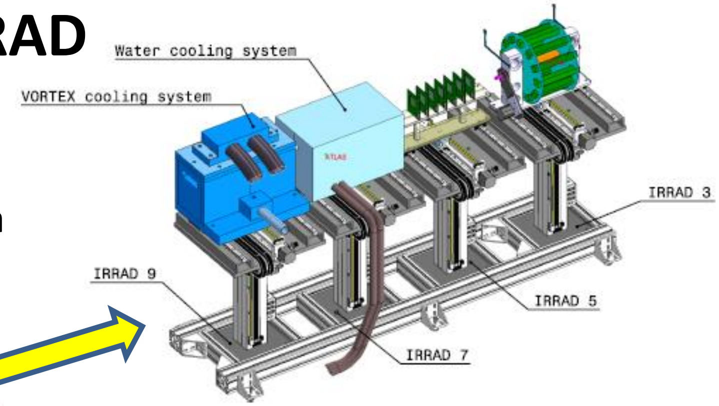
# Scanning tables for PS IRRAD

Maurice Glaser
Frederico Ravotti
Michael Moll

First production 3axis scanning table with cold box (above). Scanning table and rail system installed in beam line (below)

Proposed layout of IRRAD area

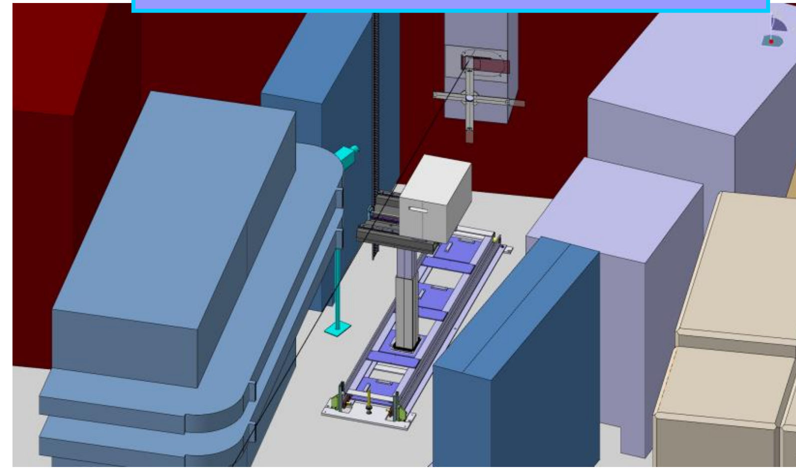





**CERN – PS** Proton Synchrotron
**24GeV Protons - up to $10^{16}$ cm$^{-2}$**
Neutrons ~ 1 MeV, $3x10^{12}$ n/hour/cm2

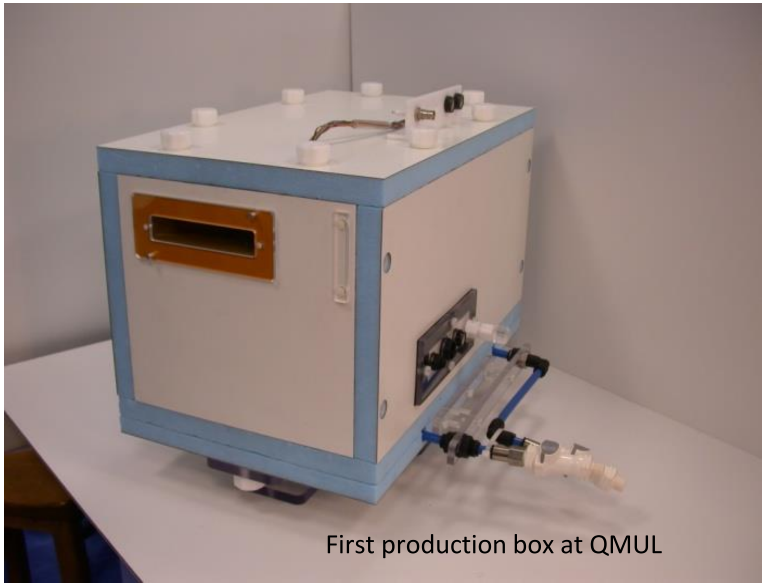
CATIA models (above) of IRRAD area with thermal box and scanning installed.

CATIA model of first installation on beam-line with rail system (right).



# AIDA Cold box Status

Box 2 in production / testing at Sheffield



First production box at QMUL

Established design & manufacture at QMUL/Sheffield.

*Status*

- Box 1 at CERN installed =ok
- Box 2 at QMUL in transit / at CERN
- Box 3 at Sheffield ready to ship
- Boxes 4&5 at Sheffield near completion
  - Small delay with boxes 4&5 (manpower)

Richard French

The University Of Sheffield.

# Cyclotron Irradiation Scanning Table

## Pre-configured XY-axis Cartesian Robot System

- It handles payloads up to 60 kg
- Speed: as low as 1 mm/s and as high as 360 mm/s (X-axis)
- Acceleration rates up to 20 $m/s^2$
- Positional Accuracy ±50 µm (X-axis)
- This motion system can execute strokes up to 450 mm in X-axis, and 400 mm in Y-axis
- System driven by NI CompactRIO Real-Time controller and AKD Servo Drives with synchronized multi-axis motion using NI LabVIEW graphical programming.

- Overall unit length with a parallel mounted motor is 598mm long to reduce working space

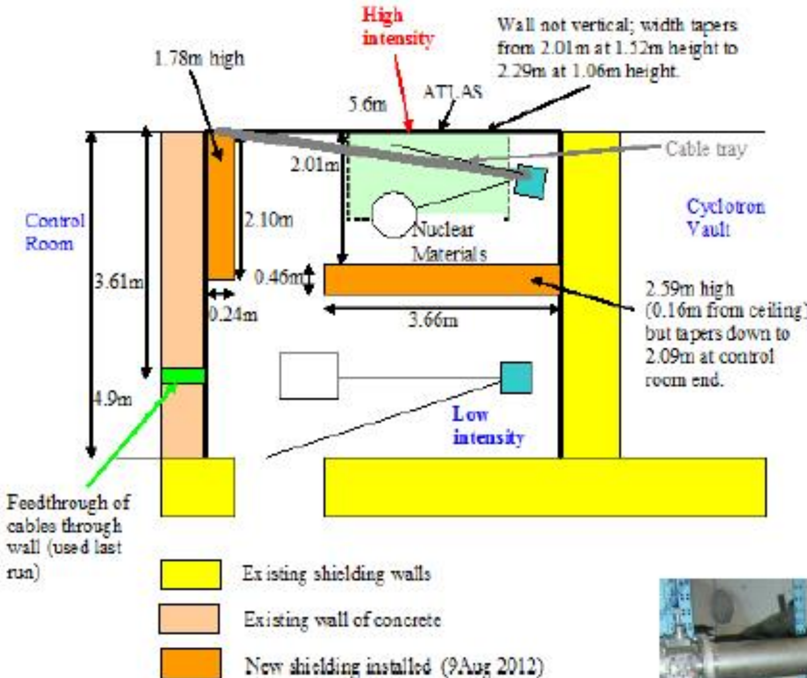
- Motors and cables connect to the scanning table in a straightforward and simple manner.

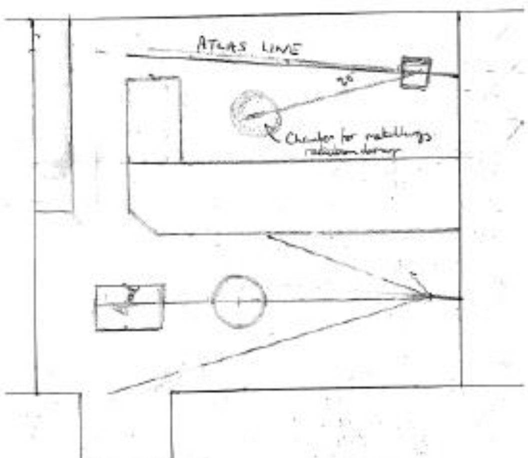
Hector Marin-Reyes, Richard French

The University Of Sheffield.

# Cyclotron Irradiation New Beam Area

## Birmingham University, UK




Richard French, Paul Hodgson

# Cyclotron Irradiation: Sensor cooling issues

## History & Details

- Radial Ridge Cyclotron – since 2004
  - Scanditronix MC40 variable energy cyclotron
  - maximum energies
    - 40 MeV (protons or alphas)
    - 20 MeV (deuterons)
    - 53 MeV (3He)

## Scanning system + Thermal Chamber

•Fully portable plug & play scanning system
•Thermal chamber using similar principle to PS IRRAD 5
  •-22C operation
  •480W heat load removal
•Readout and control system using COTS FPGA based technology
•Networked readout allowing remote access for data analysis and real-time sample performance readout.

## Current status of facility

•2010 - Irradiations performed using 26MeV protons with a beam current of 0.4mA.
•2012 – Reconfiguring beam- line for higher beam currents of >0.8mA to ~5A.
•New shielding installed to allow for higher energy running (>0.8uA) with dedicated beam line for detector activities : Completed October 2012.
•Dosimitery checks all completed
•Fully operational: November 27$^{th}$ 2012
•Over 14 months full running testing silicon sensors and materials, mainly for ATLAS Upgrade but attracting multiple users.
•Remedial work underway to complete high powered cooling system

Richard French

# Installation and test runs in 2010/11

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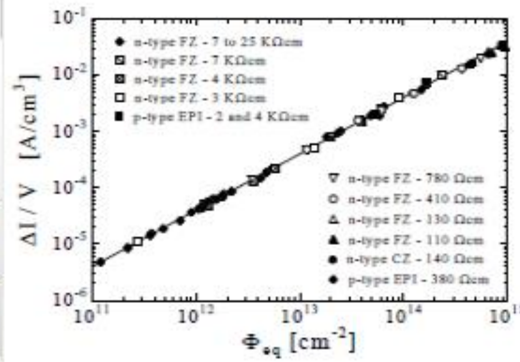
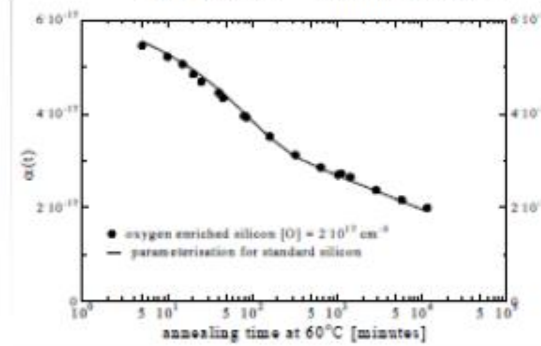
- $1cm^2$ beam spot divergence tested OK for cold box z mm
- Ti foil dosimetry
- Pad diode dosimetry
- P-in-N diode dosimetry to calibrate beam parameters.
- High dose irradiation ($10^{16}$ $n^{eq}$ $cm^{-2}$) takes 2 days
- We will soon reduce high dose time to a few hours (Aug 12) by the creation of a separate beam line dedicated high energy runs.

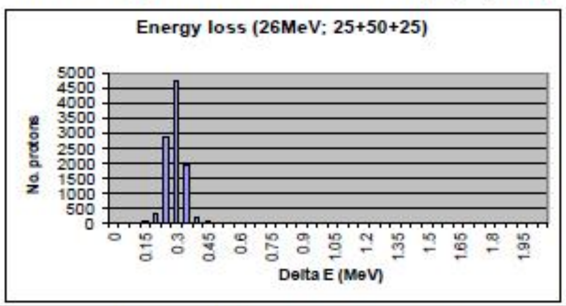
P-in-n diodes BPW 34F (SIEMENS): ΔV (mV)= $9.1\times10^9$ $n_{eq}$ $cm^{-2}$ (20ºC)

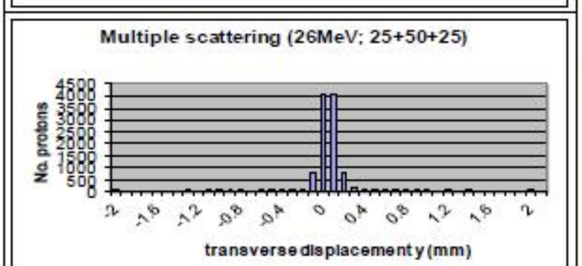



Pad Diodes 80min at 60°C




Calculating window thickness & air gap (JAW)





Initial installation, alignment and testing for first time in 2010

# ATLAS Upgrade -Fibre Irradiation 2011

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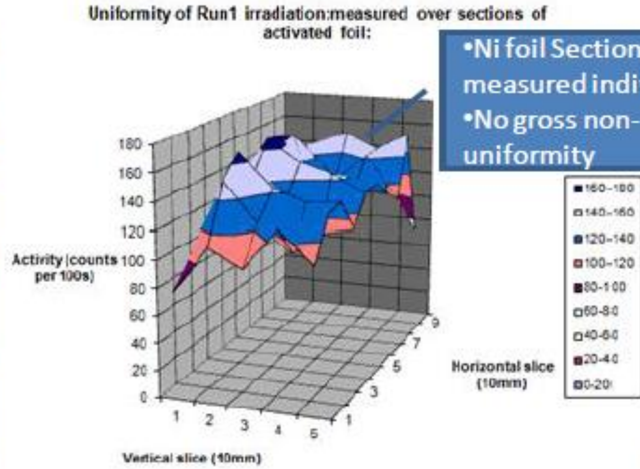
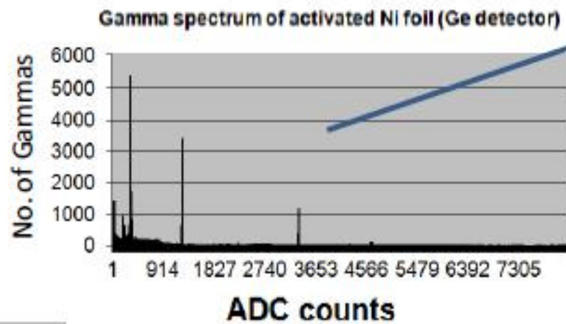
Fibre jacket holder aligned with beam on special stage

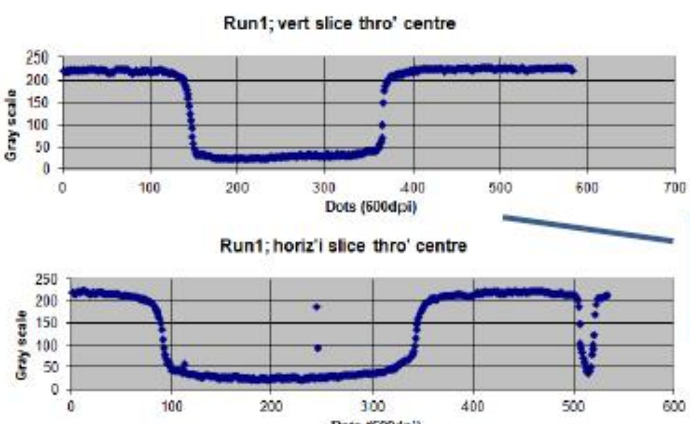



- Ni foil Sections measured individually
- No gross non-uniformity

Mounting samples in control room

- 2nd peak from the left is the annihilation peak (511keV)
- 3rd from left is the 1377keV gamma is the unambiguous signature of Ni57 decay.
- The peak is very distinct and well above background.
- Now confident of using Ni foil activation as a cross check of fluence



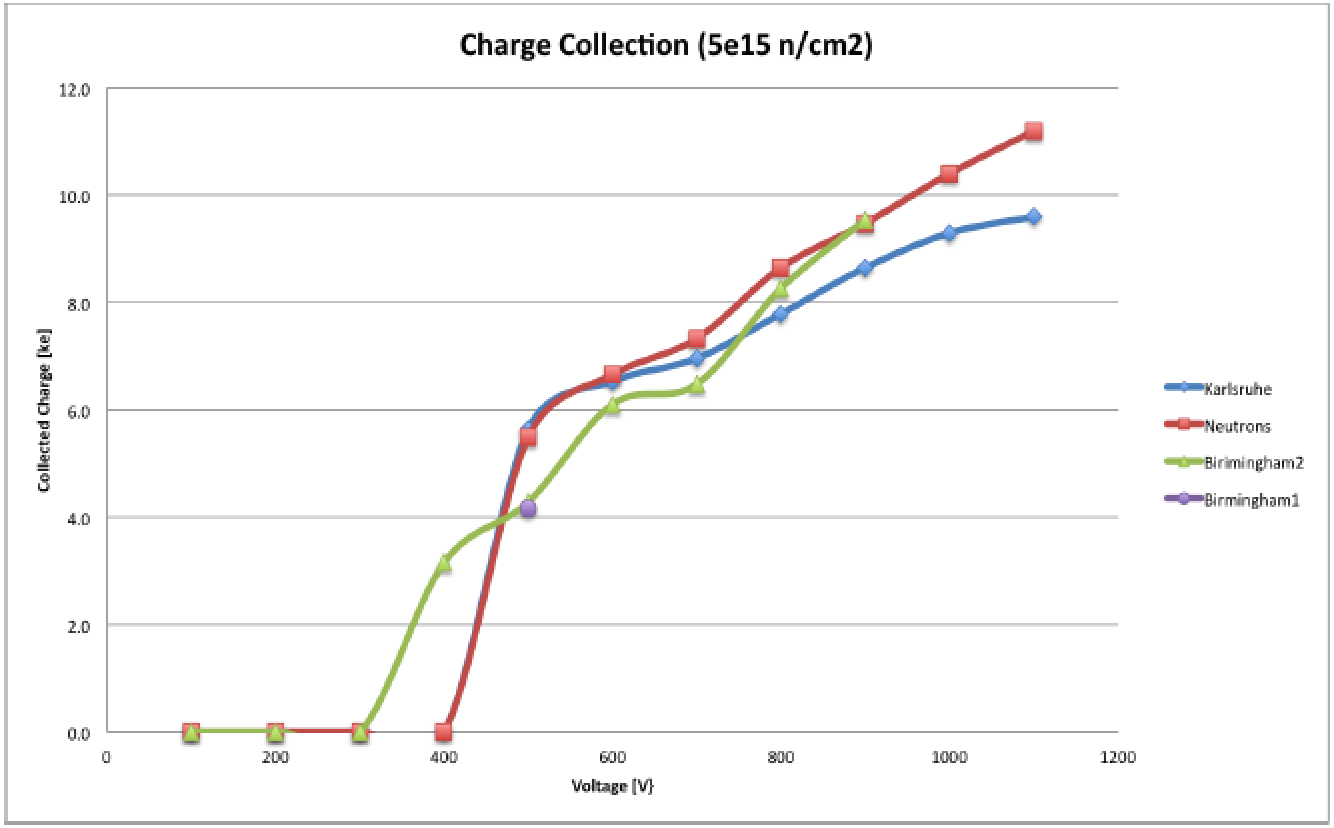

Show reasonable uniformity on Ni foil at 10% level

Alignment complete, Ni foils marked for position prior to 1$^{st}$ run.

Data - John Wilson

# Sensor cooling

- Early 2013 we spotted a sensor cooling problem when running with very high beam currents (> 0.5uA) – CCE looked ok but further tests showed anomalous results
- Low beam current running is unaffected = goal is to reduce run time
- This is due to a longer period of particle interaction with the sensor depositing energy = heat. (We do not see this with CERN PS due to higher flux).

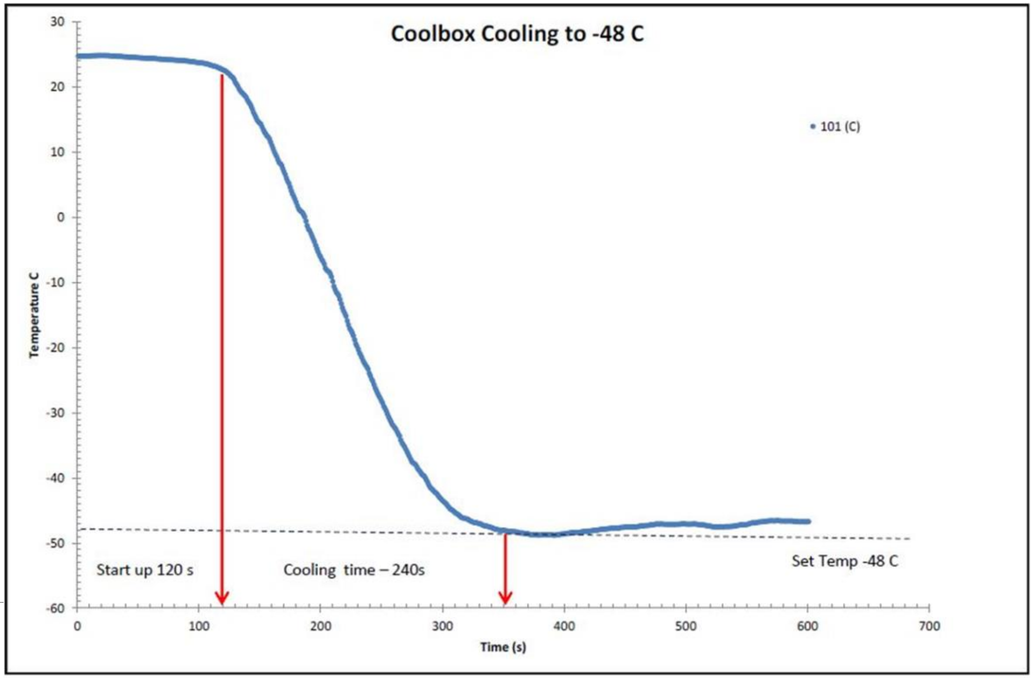


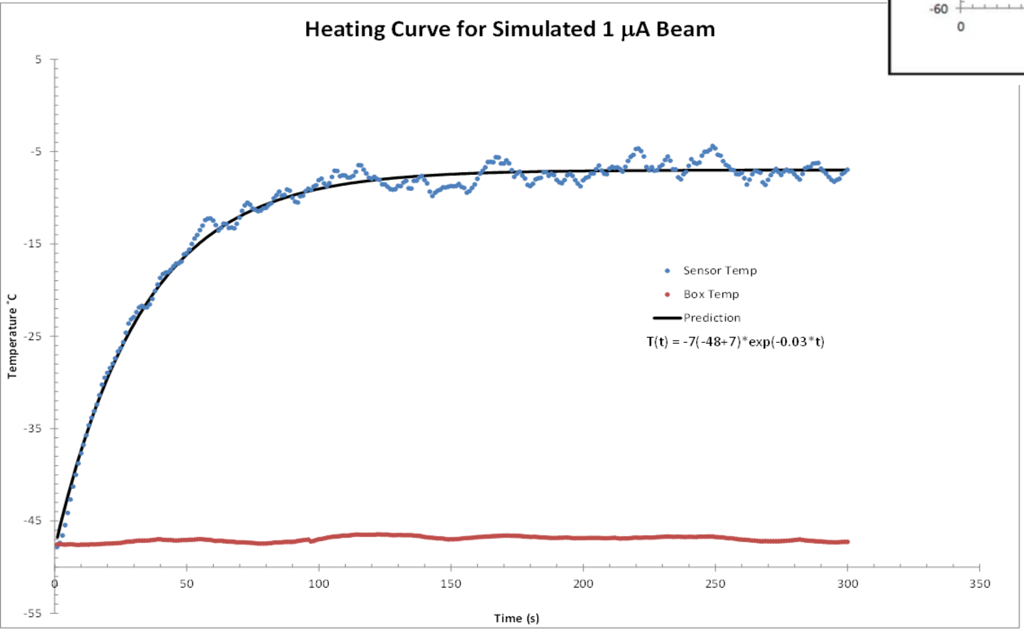

CCE measurement

Paul Dervan, Paul Hodgson, Kerry parker, John Wilson

# Solution: Forced convection cooling with LN2

- LN2 system development underway to provide ample cooling power to a new design of thermal box.
- LN2 system now operational
- Prototype box made and under test – attempting to modify existing box design with minimal modificatoin.
- Initial results exceptionally successful




- We can now provide stable cooling of silicon sensors at -48 C with no issues.
- Plan to install on beam line asap
- New box build is slow, but we should have this completed for end June 2014.

Paul Hodgson, Paul Dervan, Kerry Parker

The University Of Sheffield.

# Conclusion:

- The Irradiation Facility sited at Birmingham University has performed hundreds of successful irradiations.
- Using a higher energy beam current will reduce irradiation period.
  - Short irradiation periods = lower cost + higher capacity
  - To increase irradiation through-put requires a new LN2 cooling system.
  - LN2 cooling is now in the final stages of testing / prototyping.
- This will allow silicon sensor operation and testing during irradiation with no damage to the sensor
- Low beam current running and passive material irradiation remains unaffected.
- From end June 2014, very basic LN2 cooling of sensors during irradiation runs will be possible.
- Planned TA though AIDA 2 has been proposed to this facility,
  - Further more bespoke development of a LN2 cooled thermal box is planned for 2014 onwards (dependent on investment).