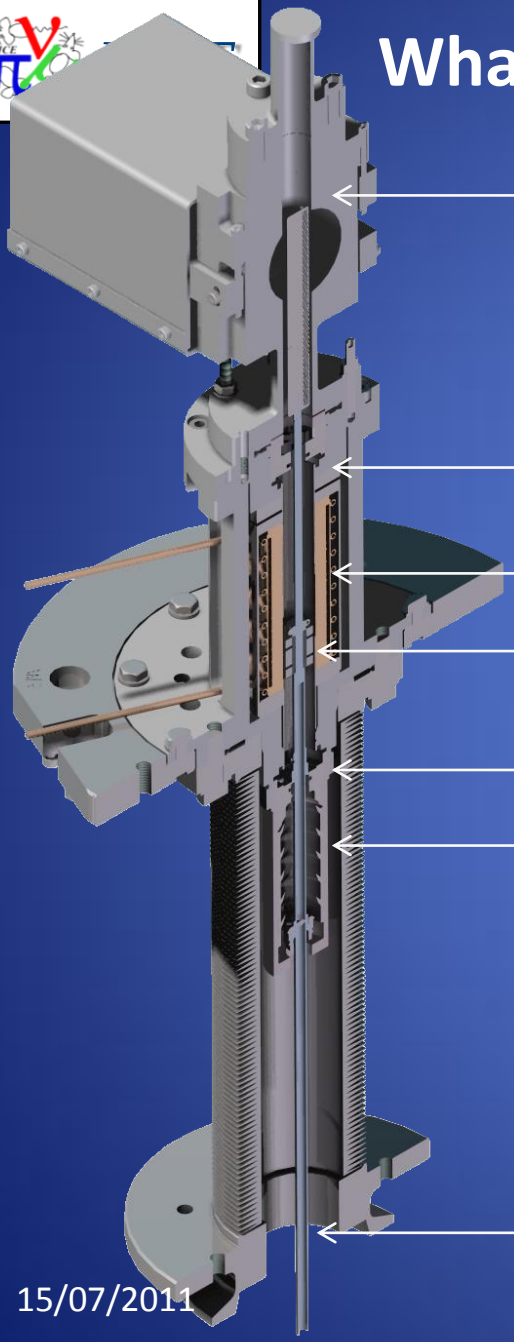
The MICE Target

Hitting the ISIS Beam to a Hair's Breadth

Paul J Smith

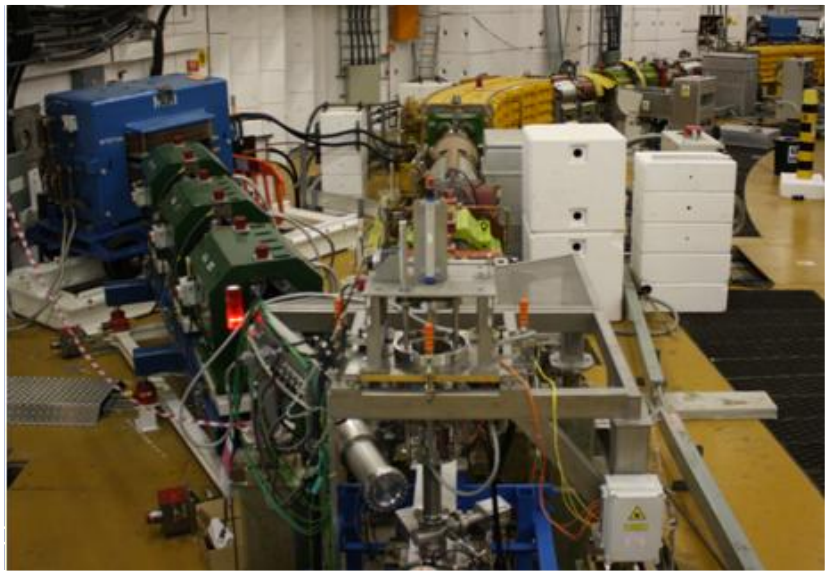
University of Sheffield

What is the Target Mechanism?



The target mechanism is an electromechanical device that rapidly inserts a small titanium target into the circulating proton beam of ISIS immediately prior to extraction without unduly disturbing the primary proton beam.

Pions created from the interaction with the target are collected by the MICE beamline where they undergo decay to muons for use in the MICE experiment.



Timeline of Developments

2003

Initial Specification Determined.

In preparing for this talk I reviewed a lot of the material that has been produced for the collaboration over the last 7 years.

The following slides are mostly a photo album tour showing the highlights of the development of the MICE Target.

Original Specification - 2003

A lot of the figures for the original specification were 'best estimates' based upon what was known at the time and from operation of the old HEP target on ISIS.

- Enter last 1-2 ms of beam.
- Not disturb next injection.
- Resonant system disfavoured. On demand actuation preferred.
- Baseline frequency of 1 Hz.
- Travel estimated 25 mm but variable
- Required entry into beam estimated 5 mm.
- Reproducibility 0.2 mm.
- Accurately synchronised to ISIS, drift/jitter 0.2 ms.
- Slit across beam pipe 2 mm wide max.
- Target titanium 1 mm across beam, 10 mm along.
- Radiation hard, UHV materials.

It was estimated that it would require 1.4 E12 protons out of 2.5 E13 protons per pulse to interact with the 10 mm length of the target in order to generate 600 good muons per intercepted spill.

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- Particles are of right energy for MICE
- Reduces losses for ISIS which nominally operates at 50 Hz.

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Initial studies indicated that an electromagnetic linear motor was the best way of achieving these objectives

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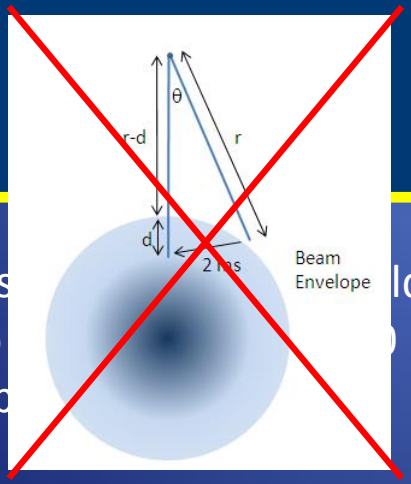

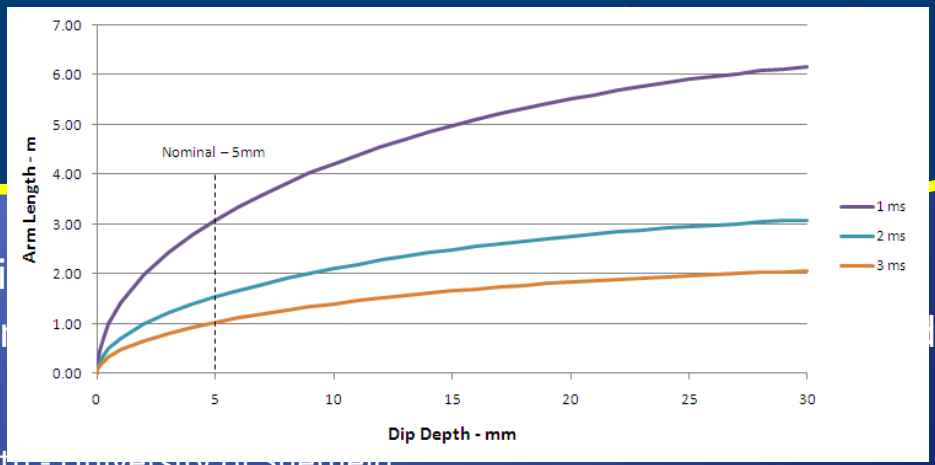

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Hair's Breadth!

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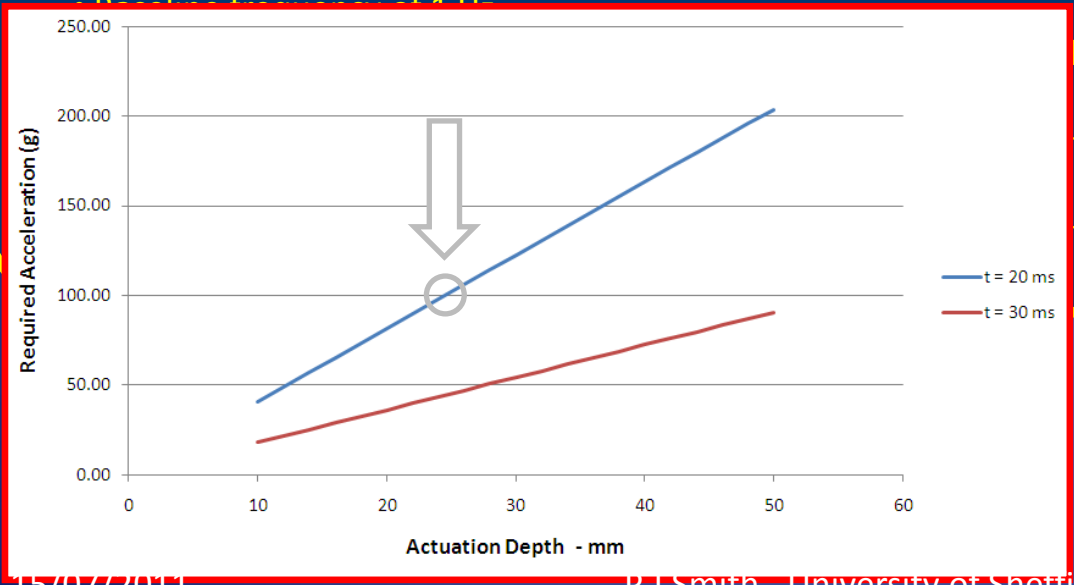

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- Not disturb next injection.
- Resonant system disfavoured. On demand actuation preferred.
- The requirement for a 2mm wide slot was later not necessary as the target was given a port, but this requirement drove the initial design of using a blade. Also another reason to preclude the use of a rotary target system.
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- Required entry into beam estimated 5 mm.
- Reproducibility 0.2 mm.
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Solving this problem has been the hardest!

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First stator built - 6 coils – Heavy magnets ~100g.

Initial development of some basic control & power circuits.

2005

Diaphragm springs developed.

Electronic quadrature encoder trialled.

Magnetic Hall encoder trialled.

nents

- This stator was known to be inadequate.
- The diaphragm springs were not stiff enough and added too much mass.
- Quadrature Encoder was good but we needed an optical, non-contact version.
- A Basic DAQ was built.

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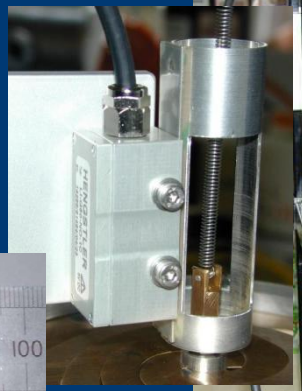

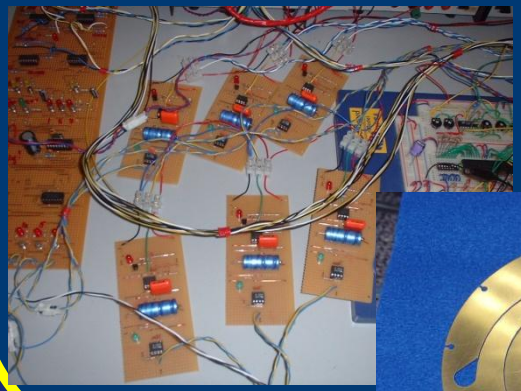

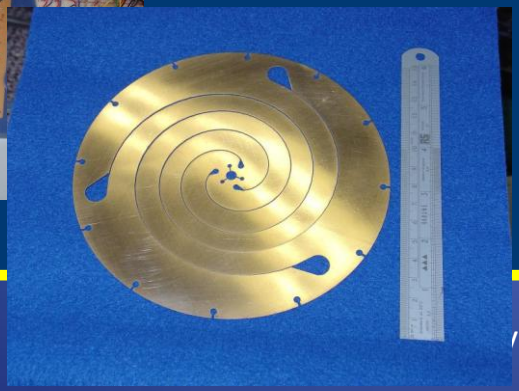

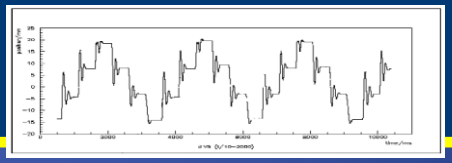

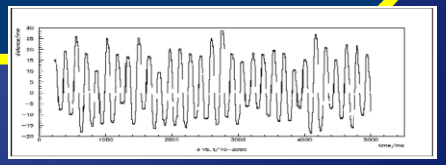

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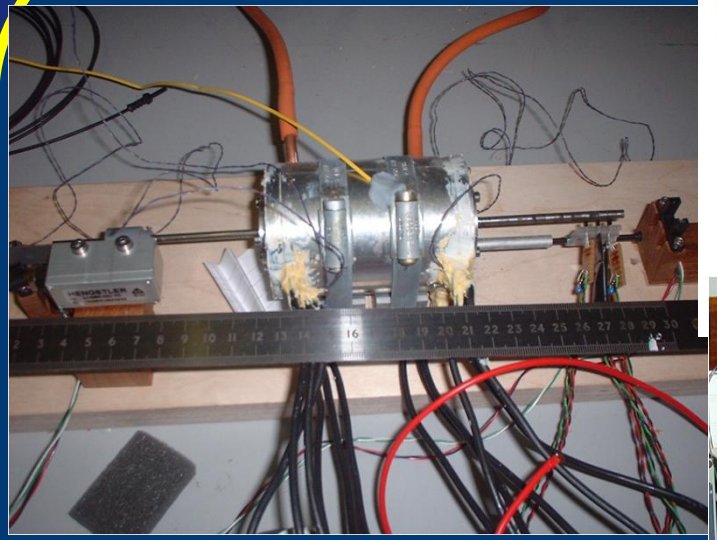
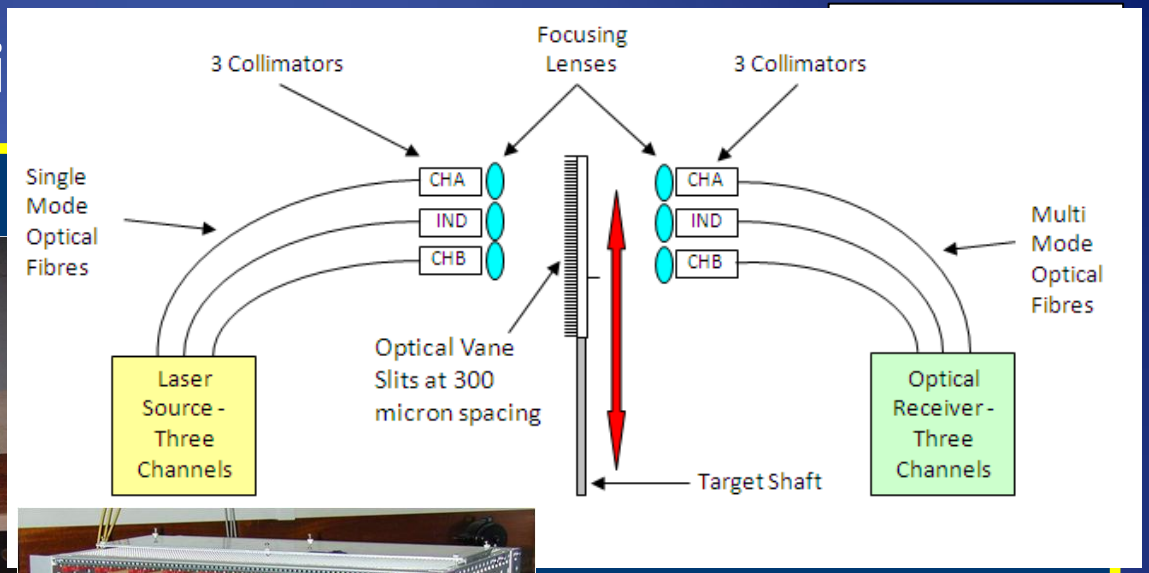
- **New stator (24 coil design).**
- **10A power supply.**

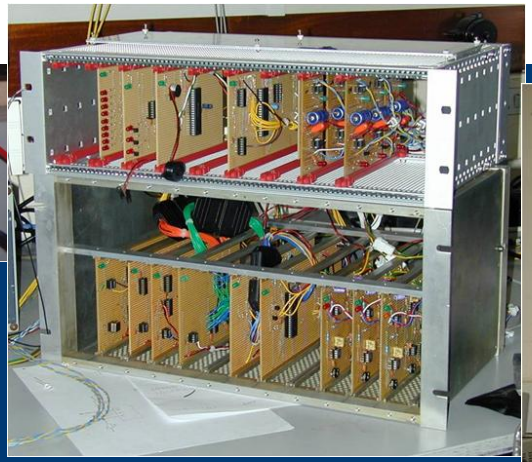
2006

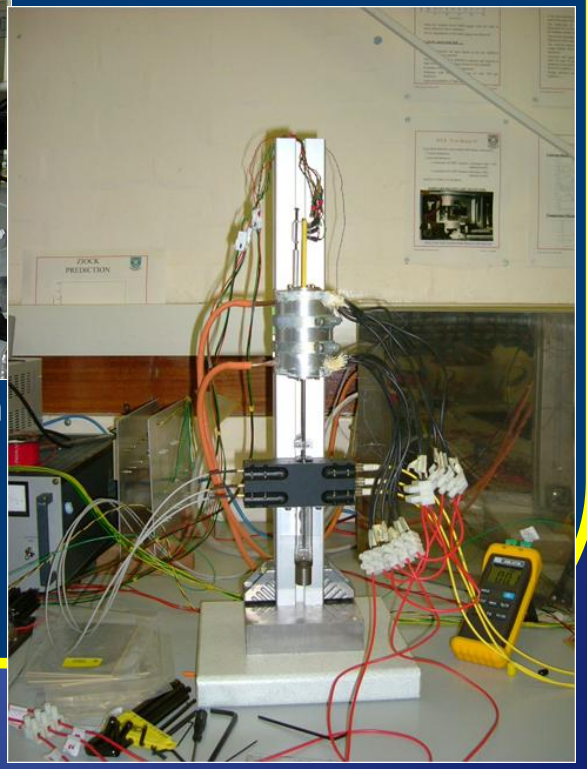
- **Quadrature encoder turned into an optical system – 150µm resolution**
- **Control electronics developed – PIC based.**
- Cruciform shaft & full optics block
- RAL R78 assembly tests & first target tests on ISIS

Timeli









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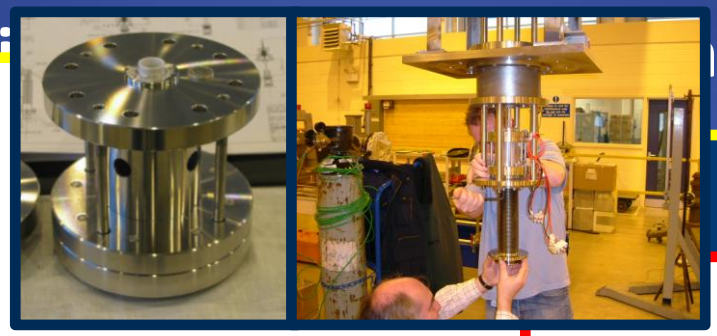
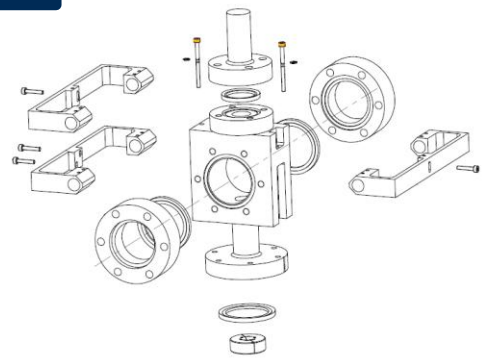
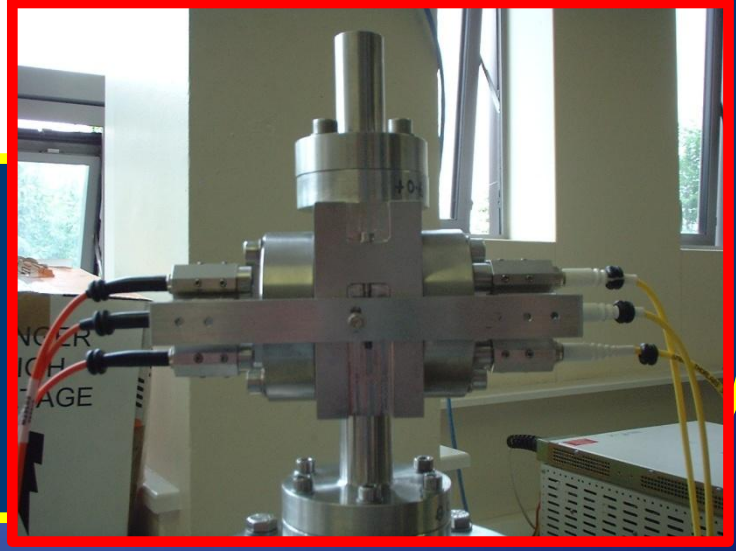
Ti...ts







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- Control Electronics Developed
- **Cruciform shaft & full optics block**
- **RAL R78 assembly tests & first target tests on ISIS**

Timeline of Developments

2006 Target Tests performed in the MICE Hall.

Aimed to Understand

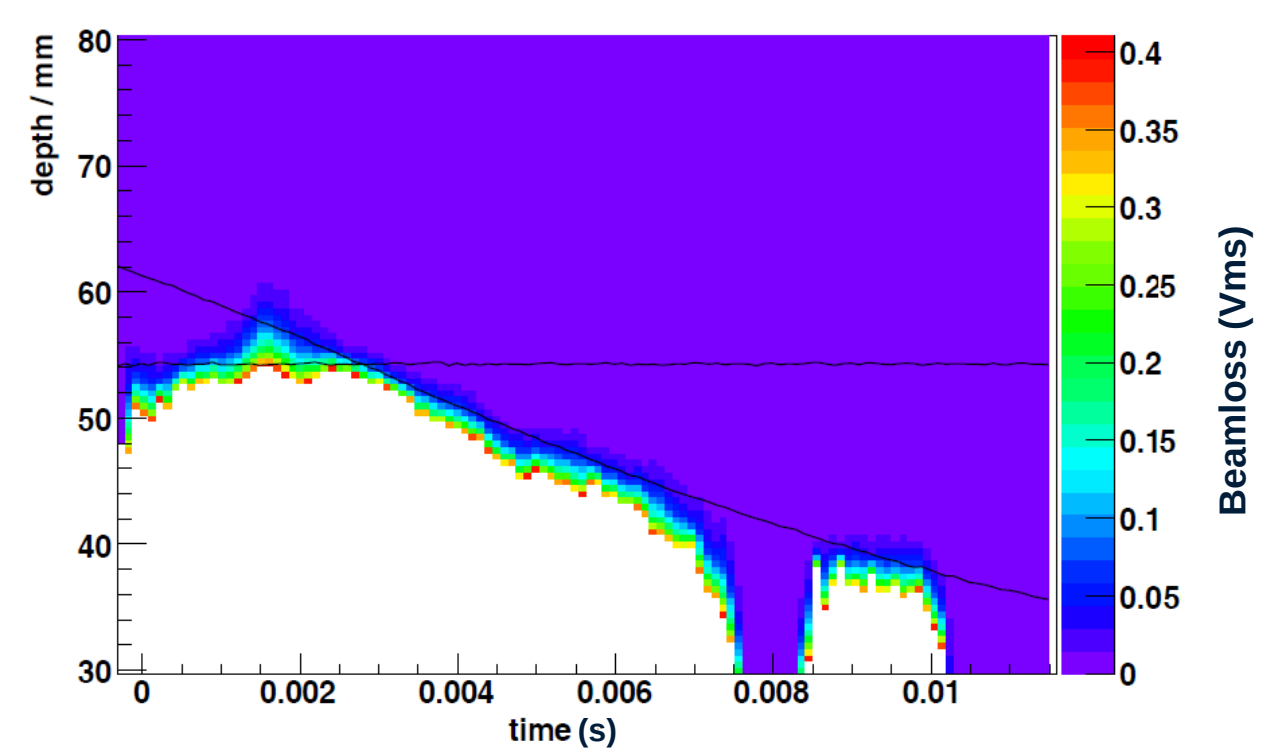
– ISIS beam profile (r,t)

– Beam loss caused by the new target

What we were not trying to do:

– It was not the aim to test the final target (as this didn't exist!) but to learn how well the current prototype matched the assumed ISIS parameters.

2006 Target Tests



MICE Note 165:
Analysis of Target Beam Test Data
http://mice.iit.edu/micenotes/public/pdf/MICE0165/MICE0165.pdf

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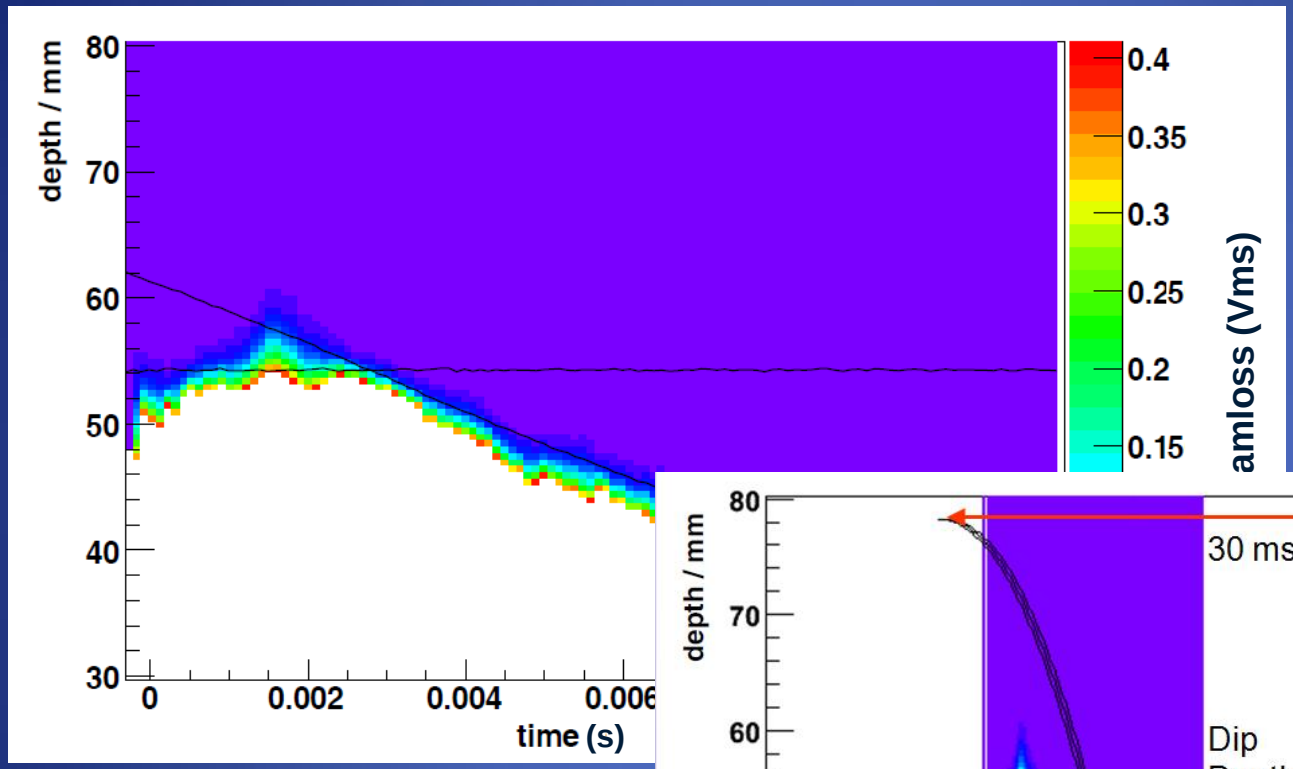

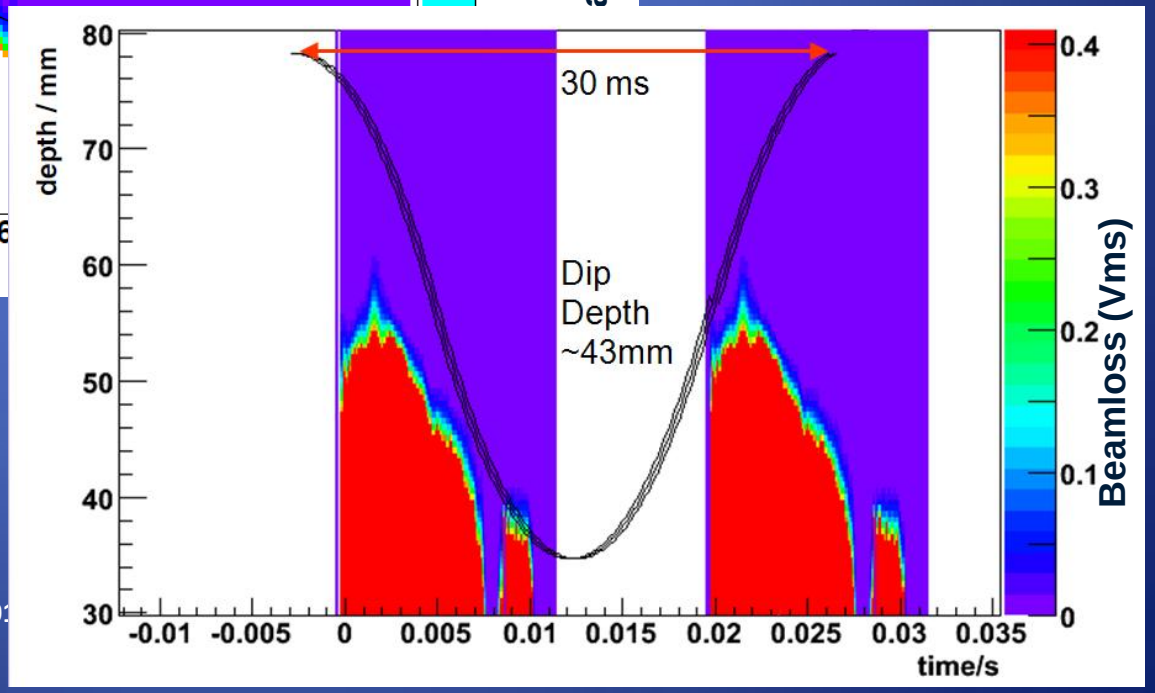

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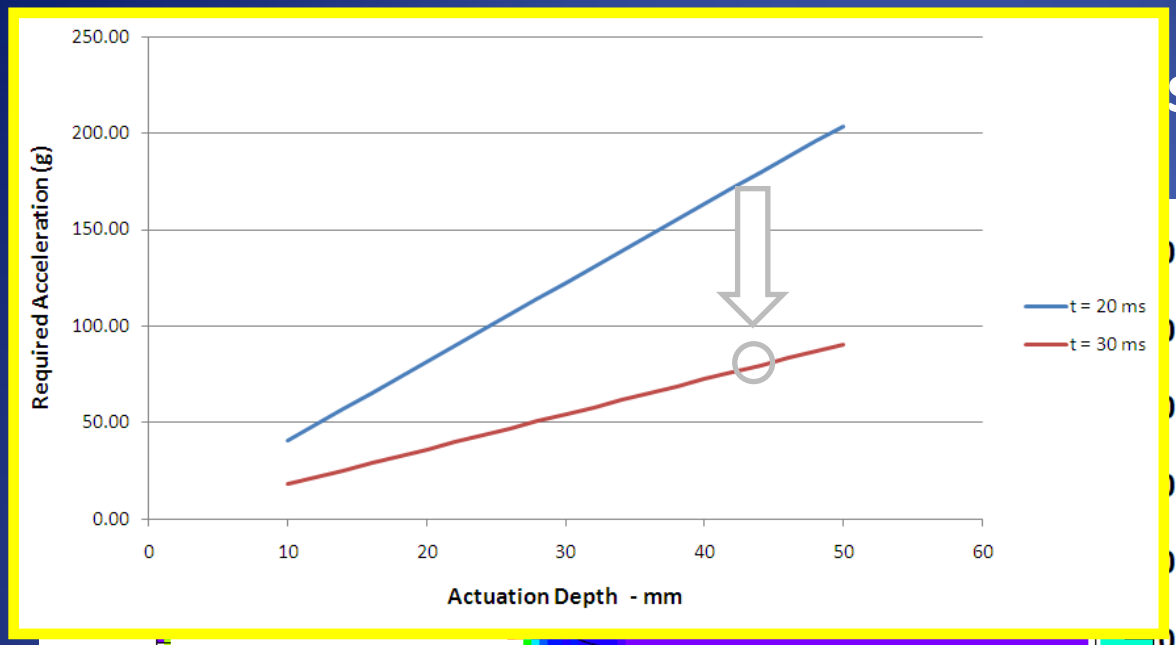

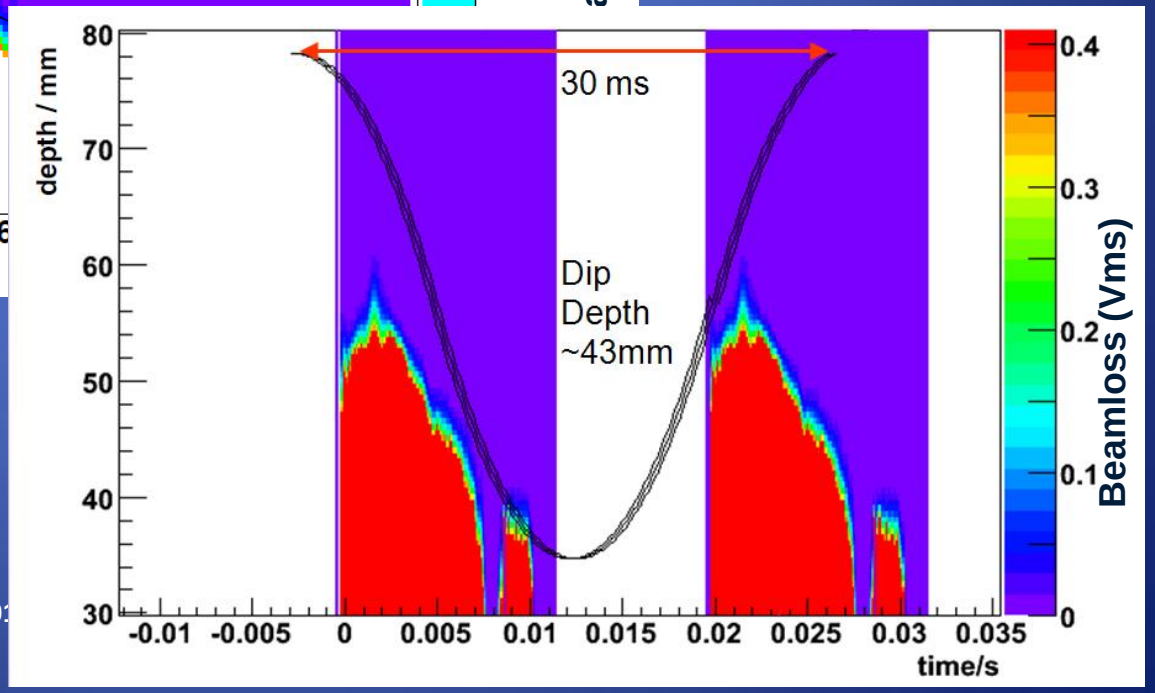

The University Of Sheffield.

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Timeline of Developments

2007

New Power supply designed to supply currents of 60A to stator via capacitor banks.

Control algorithms adopted to deal with higher accelerations.

Bearing tests performed at Sheffield Revealed Ceramic bearings to be inadequate

Bearing Trials – Found Diamond Like Carbon (DLC) on DLC gave the best results.

First 'Installation Ready' target control system completed.

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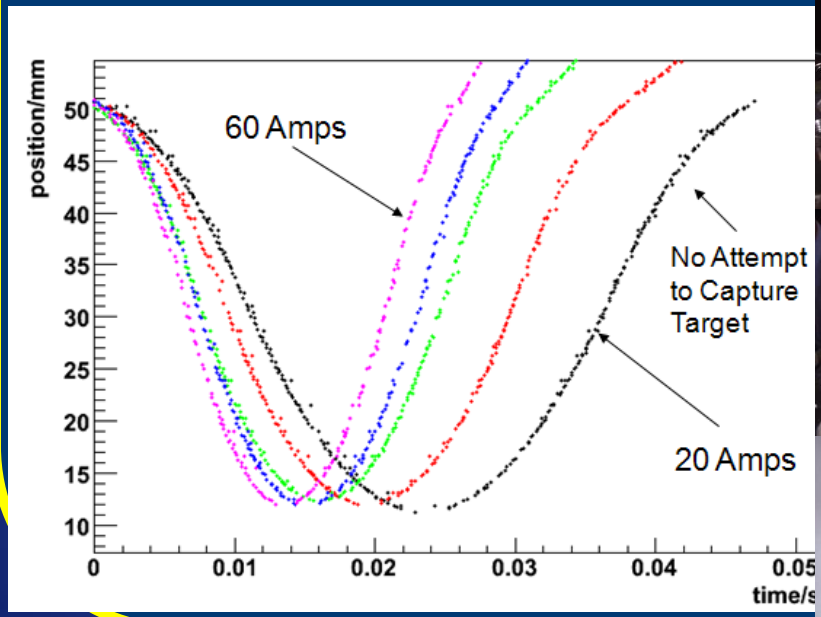

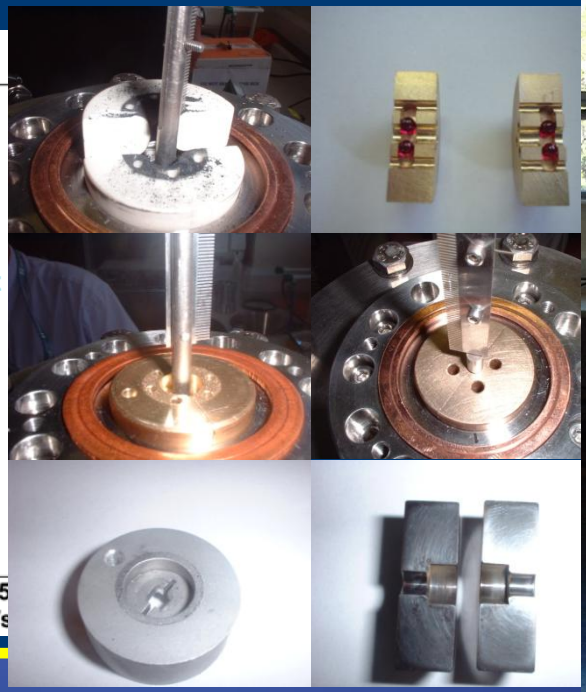

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2008

First Target (T0) Installed on ISIS in January – Target ran until Dec 2008 (190K pulses).

Running Tests with Demonstrator Targets R78 revealed electrical problems with design.

Split Power Supplies Designed to reduce voltage stress – Improved QA on coil testing.

New Target produced and Run in R78 – performs 340K actuations before bearing failure.

Jason Tarrant Joined the Target team to improve the mechanical design.

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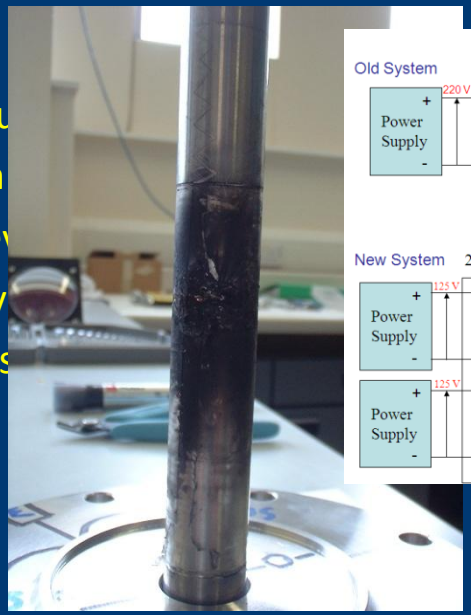

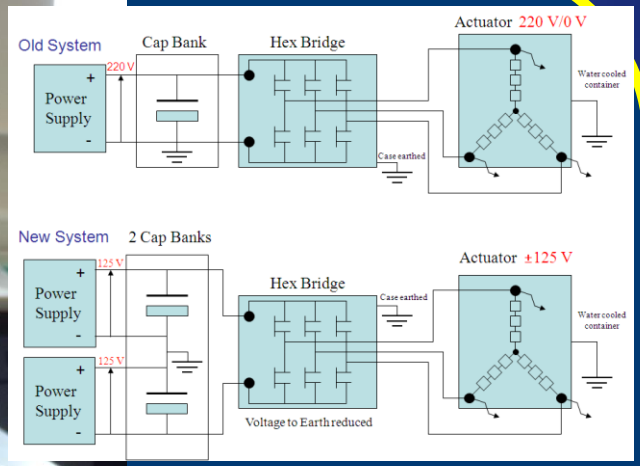

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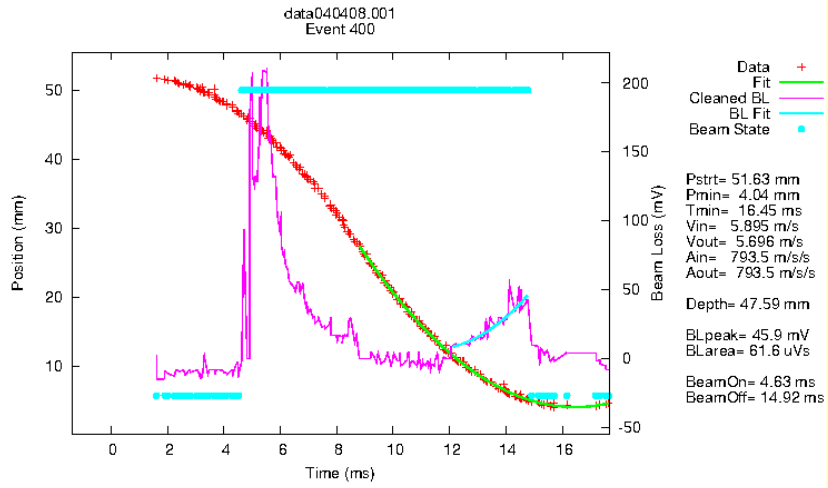
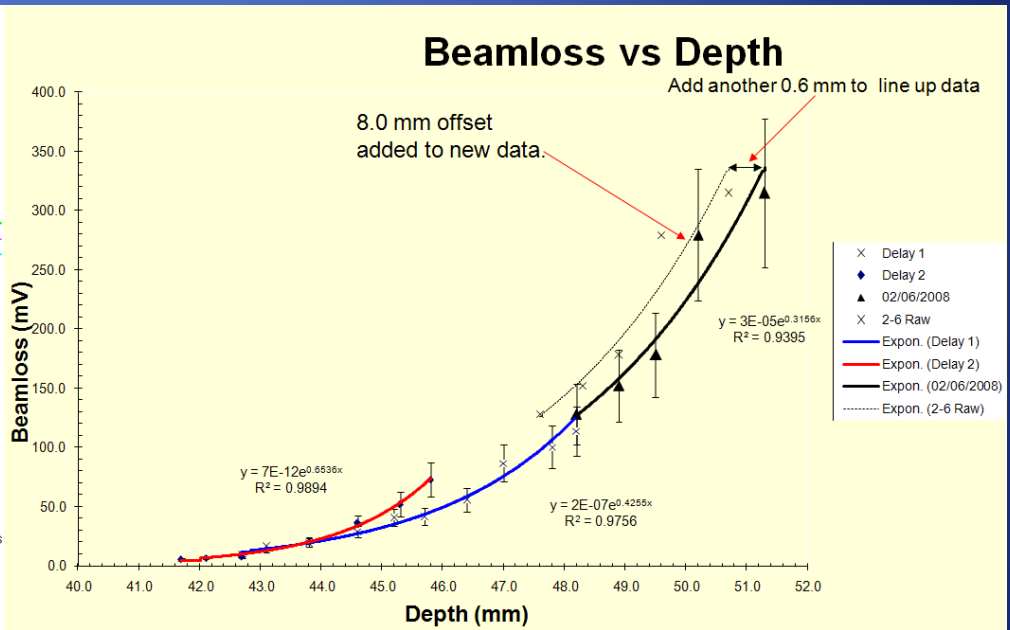
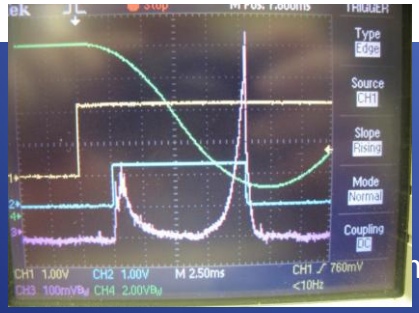
T(0) Operations

T(0) Mapped Beamloss vs Target Operation.
Permitted commissioning of the MICE beamline (190K Actuations).
More in the next presentation on what MICE has done with the targets!







Target was broken in Dec 2008

Timeline of Developments

2009

- **Cruciform shaft design changed to a cylindrical design.**
- **Bearing design changed.**
- **Second stator (T1) tested and installed on ISIS (August 2009)– DLC on DLC .**
- **Controller upgrade - Phase 1 started.**
- **Stator tests T2.1 and T2.2 in R78.**

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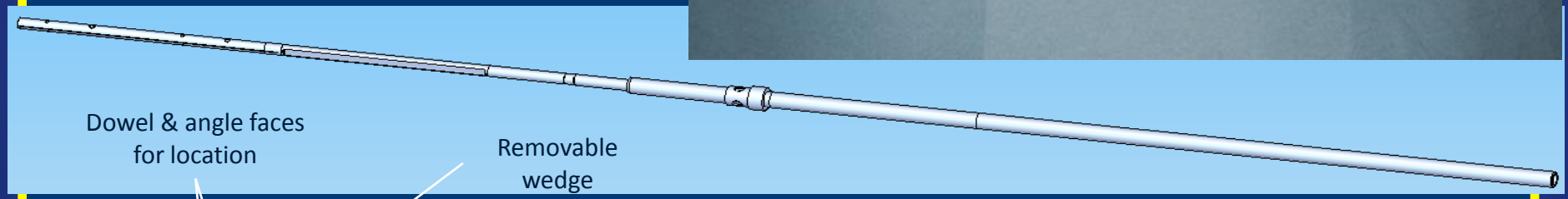
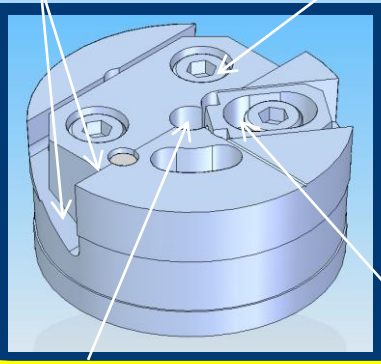


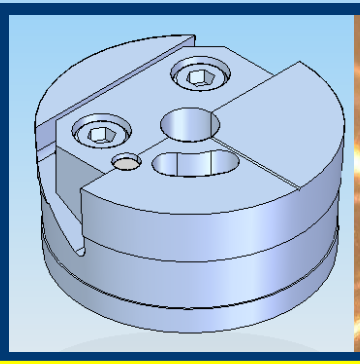
Dowel & angle faces for location

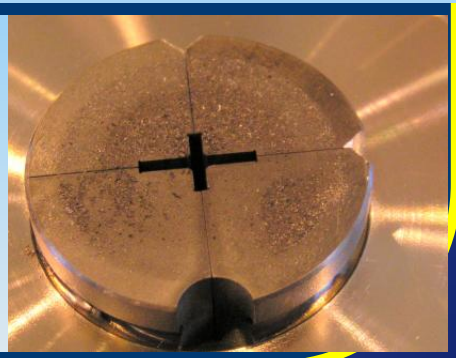
Removable wedge



Bearing hole

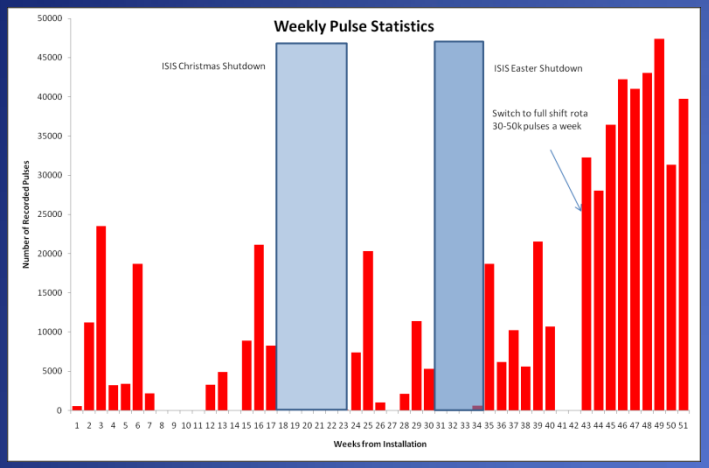
Rotation stop



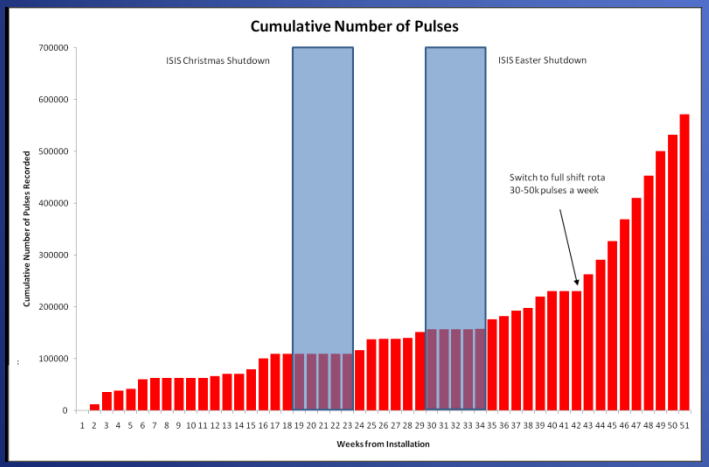


T(1) Operations

Pulse Statistics



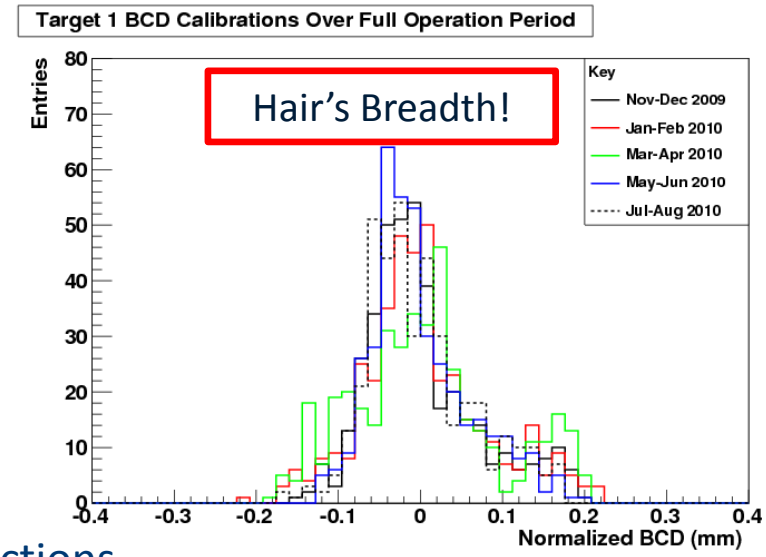
571k pulses in ISIS (620k total)



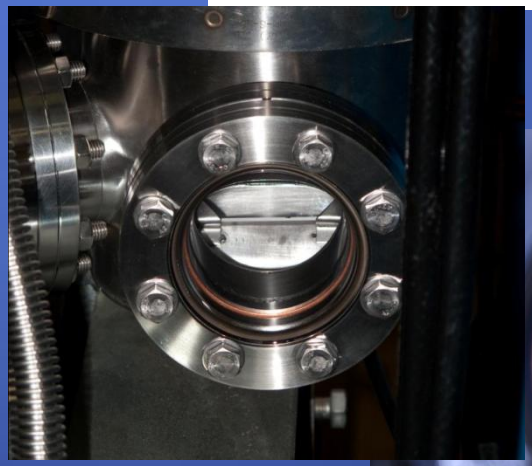
Continuing to use T1 during 2011

15/07/2011

Calibration Plots

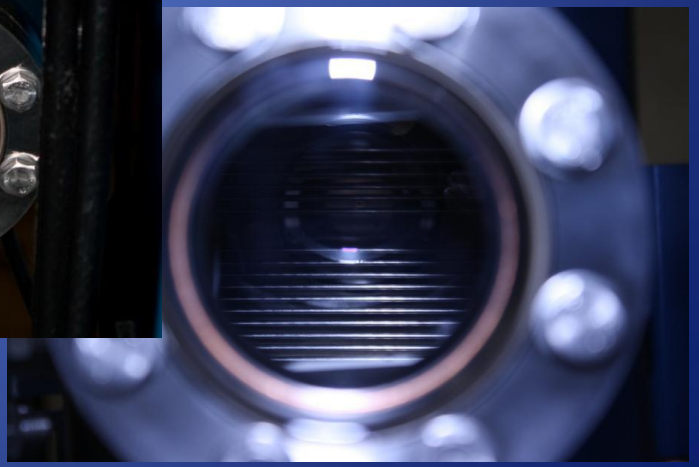


Visual inspections



27th Aug 2010

7th Sept 2009



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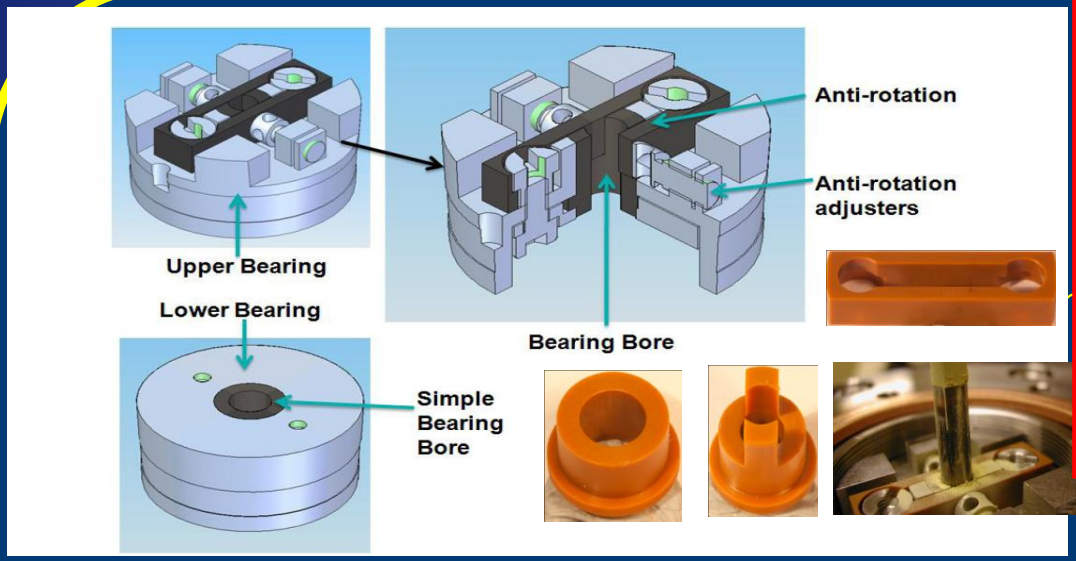
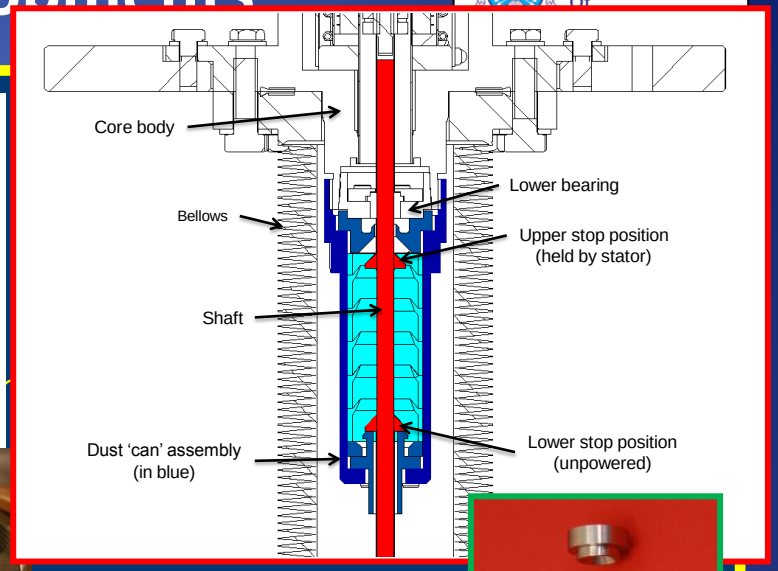
2010

- **Magnetic mapping of stator showed deviation in T2 of magnetic axis**
- **Started testing Vespel bearings with DLC shaft**
- **Controller upgrade Phase 1 completed and commissioned in R78**
- **Controller upgrade Phase 2 started**
- **Addition of a 'Dust Catcher'**

Timeline of Developments





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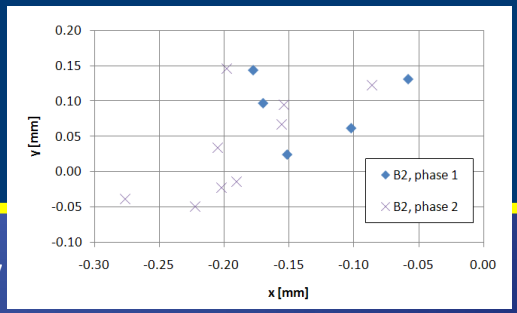


Timeline of Developments

2011

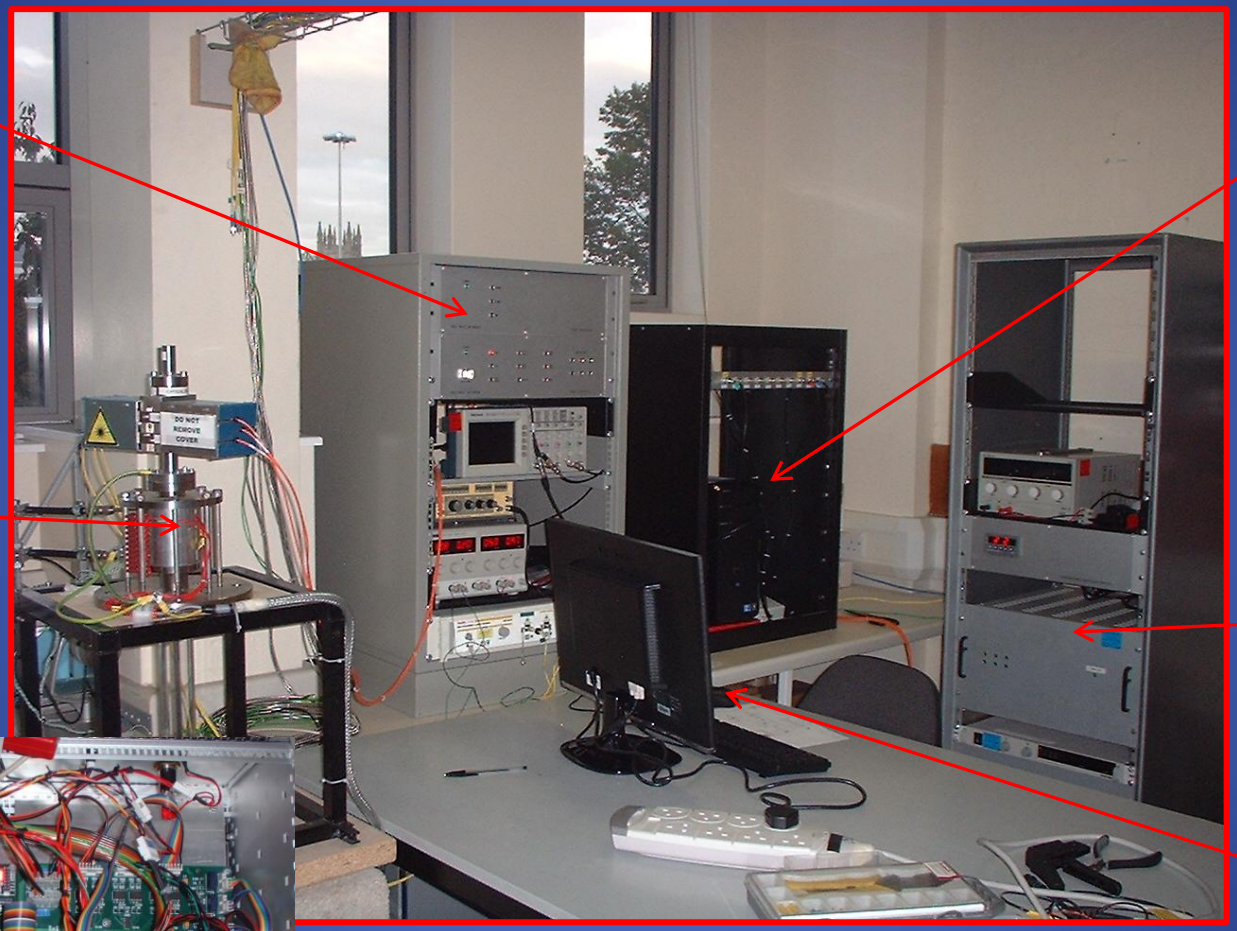
- **Controller Phase 2 Commissioned.**
- **Significant testing of Vespel Bearings.**
- **Redesign of the stator core and the coils is underway.**

We'll take look at these individually...

Target Controller

Target Controller

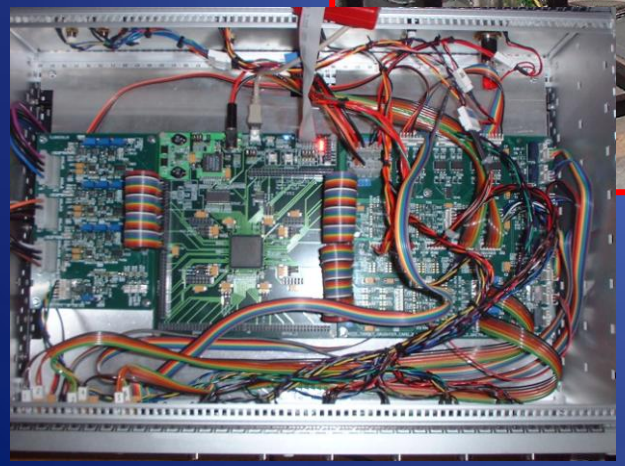
Target (Older design)



DAQ & Target Control PC and DAQ electronics

Target PSU And Temp Monitoring

Target User Interface!

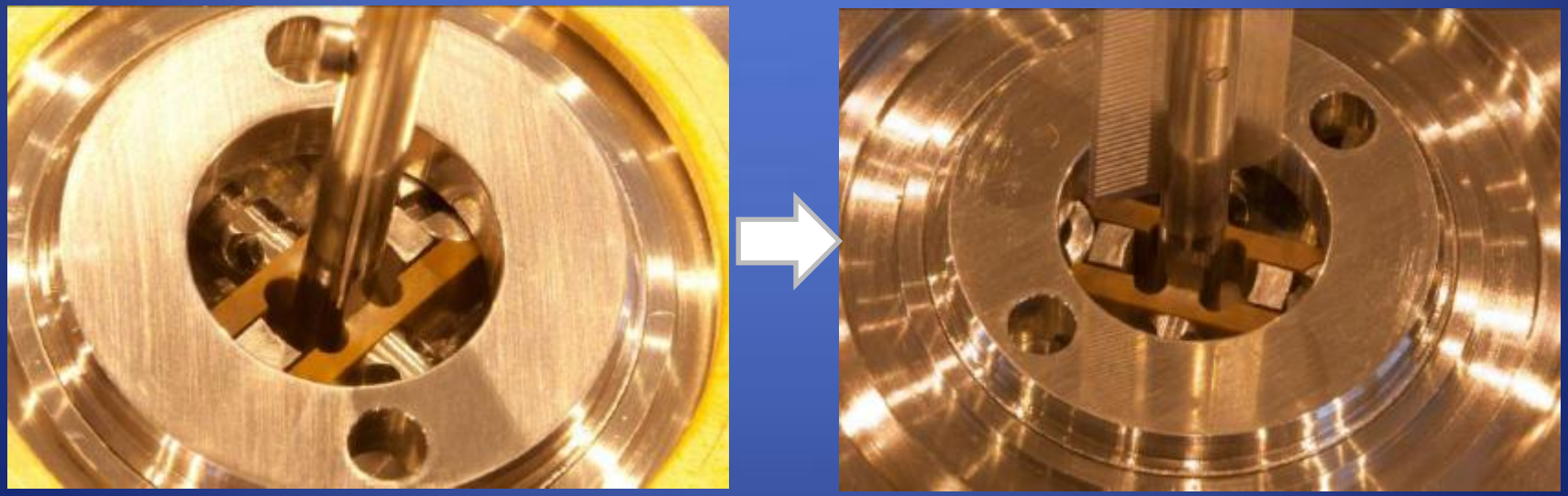


Target Setup at Sheffield

R78 Tests (T2)

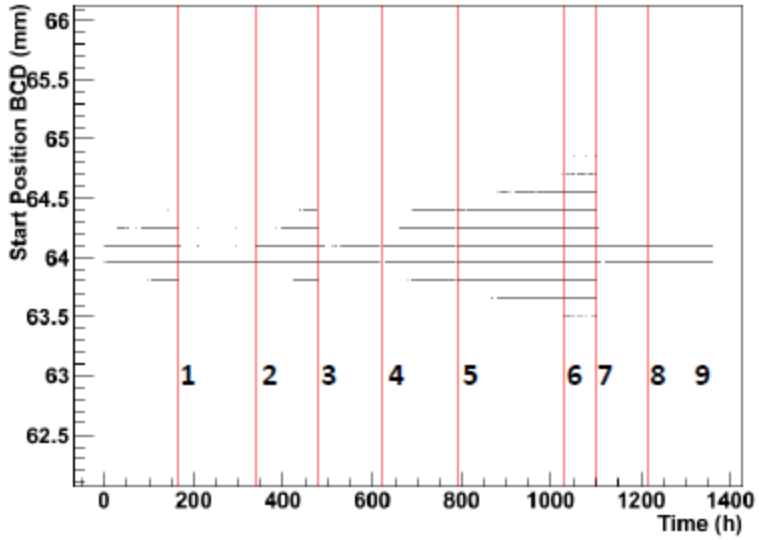
Target Number	Design	Pulses (k)	Clearance um (Diameter)		Comments
			Top	Bottom	
2.1	DLC/DLC	1	50-80	50-80	Old DLC Bearing Design
2.2	DLC/DLC	80	50-80	50-80	Old DLC Bearing Design
2.3	DLC/VESPEL	2100	50-80	50-80	New Vespel Bearings but Poorly Finished Flat
2.4	DLC/VESPEL	1000	50-80	50-80	Improved Shaft, Minimal Dust, Wear in Corners
2.5	DLC/VESPEL	4000	30	30	Bearing Cutouts, Minimal Dust, Weekly Inspections
2.6	DLC/VESPEL	1100	15-17	20-23	No Weekly Inspections, Some Sticking
2.7	DLC/VESPEL	1300	20-25	35-40	Bearing Clearances Increased, No Inspections, Some Sticking
2.8a	DLC/VESPEL	1100	25-30	45-50	Bearing Clearances Increased, No Inspections, Some Sticking
2.8b	DLC/VESPEL	**TBA!**	25-31	45-51	New Controller - Using 2.8a - Will Capture Sticks be Reduced?

T2.5 before/after 2.3 million actuations



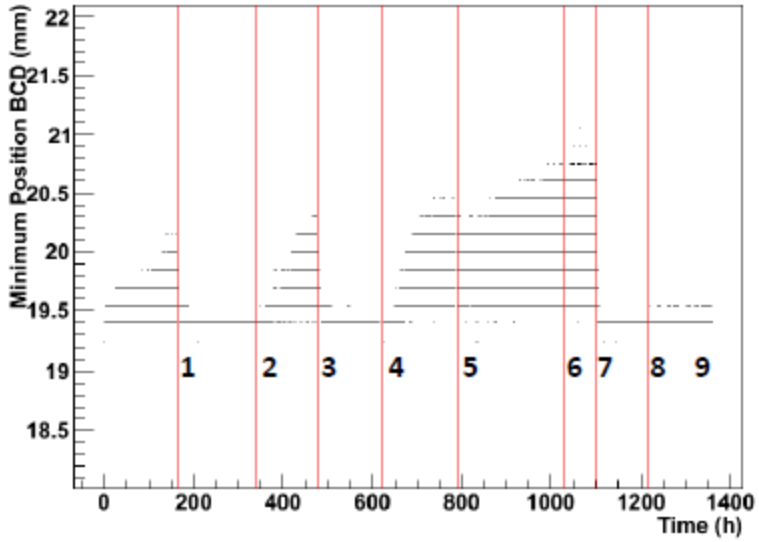
T2.5 – DLC/Vespel – 4.0 million pulses

Raw Data from Start Pos BCD

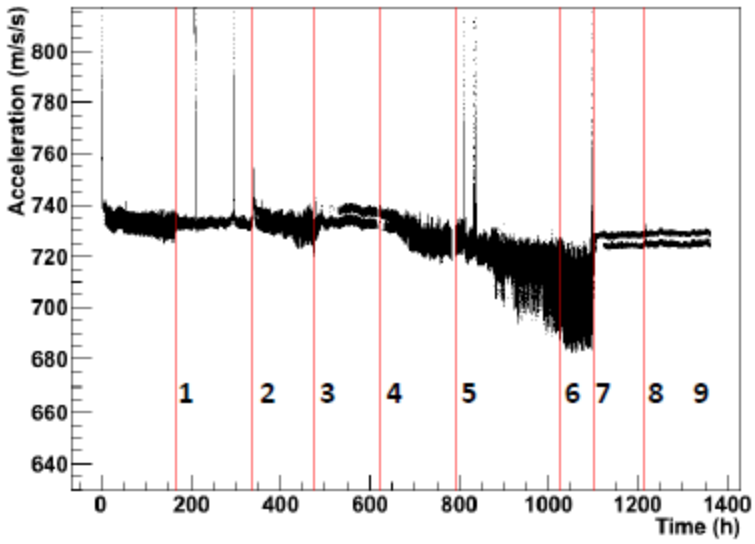


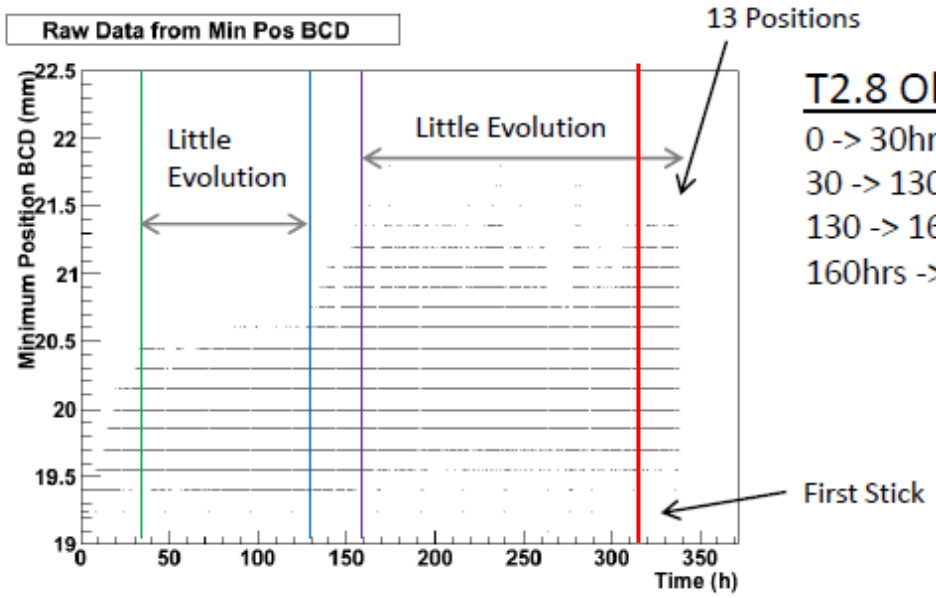
Stop Time	Actuations	Description
1 - 164	490960	Inspection 1 (14/12/2010)
2 - 338	512865	Pause for Christmas, Inspection 2 (5/1/2011)
3 - 476	412043	Inspection 3 (11/01/2011)
4 - 621	414325	Inspection 4 (18/01/2011)
5 - 790	482527	Inspection 5 (26/01/2011)
6 - 1026	701662	Test Pause in running park for 1hr. (attempt reset)
7 - 1101	219747	Inspection 6 (17/02/2011)(CM29)
8 - 1214	334982	Pause, DAQ pc full
9 - 1361	436588	Final Stop (no line, end of data)

Raw Data from Min Pos BCD



Acceleration to SP1



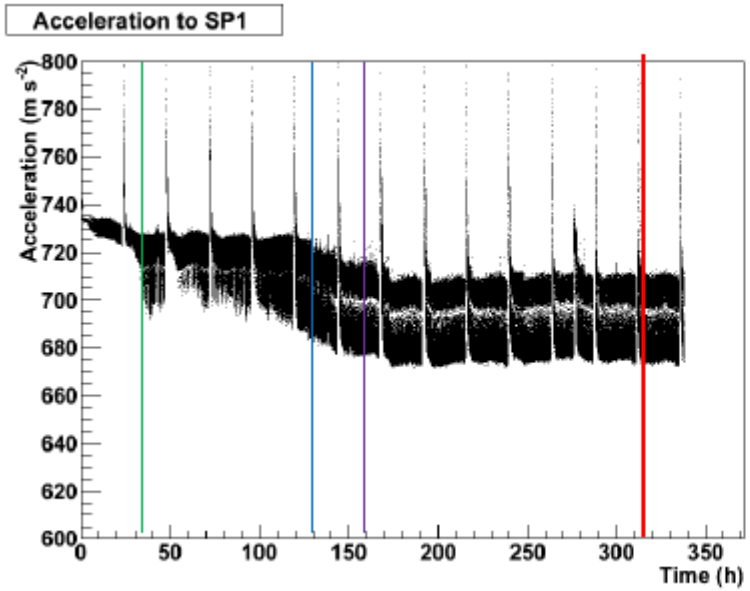


T2.8 Observations:

0 -> 30hrs:	Rapid increase in number of minimum positions.
30 -> 130hrs:	Little / no increase in start position
130 -> 160hrs:	Rapid increase in number of minimum positions.
160hrs -> now:	Apparent flat, some dips

The Vespel bearings are showing broader distributions that the DLC/DLC. This is currently being investigated. Techniques are being tried to mitigate the effects of this.

Example of Plots from DAQ



T2.8 Observations:

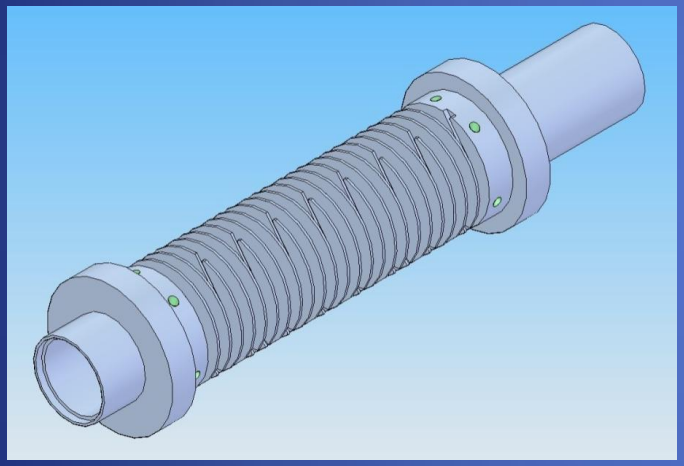
- Acceleration shows continuous change unlike start and minimum positions.
- Double distribution appeared during flat period (30-130) in start, minimum positions.
- Now two distributions occurring in acceleration.
- At 270Hrs Spike in acceleration, performance during this period was close to performance at 10Hrs.

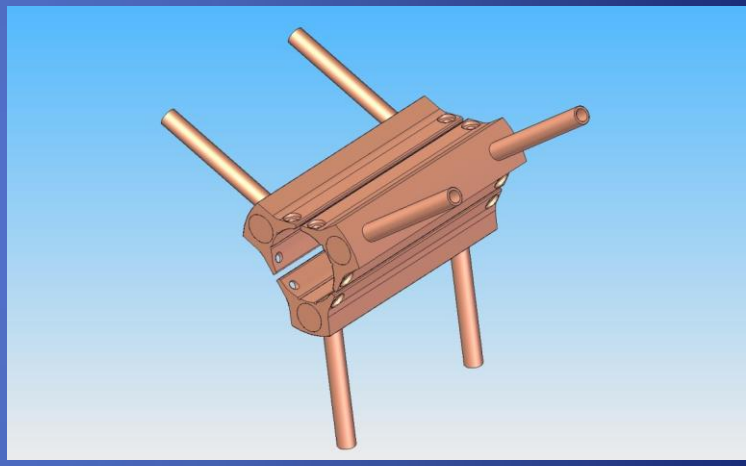
Stator Core Redesign

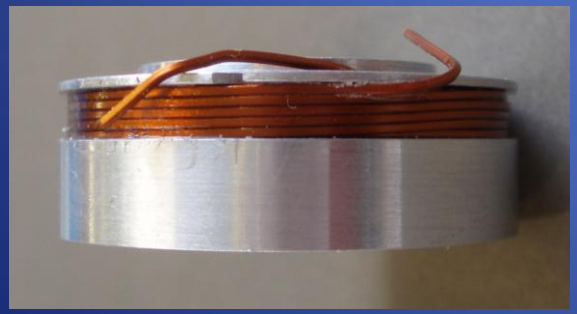
Evidence of off axis forces leading to a redesign of stator core –

Improving tolerances/QA. -> Reducing Off Axis Forces

Improving the heat sinking capacity -> running the target cooler has major benefits.







Coil Wound using Square Wire. Design changed to improve the coils magnetic symmetry/reproducibility.

Future Work

New Stator Design to be built and tested and commissioned.

New bearing materials, can we improve on Vespel?

Improve the longevity of targets through both incremental improvements in design and control

- 1 million Actuations = 6 weeks of running 8 hours a day 7 days a week @ 1Hz
- It would be great to get this to 4M+ consistently

Working with ISIS to improve particle production/reduce losses eg a beam bump

Making the target work harder:

- Changing the actuation profile.
- Halbach Arrays - > Improve the magnetic coupling of the stator to the magnets.

Improve the current Target DAQ (interface to ISIS)

Addendum

- Target T1 on ISIS became non-operational on Wed of this week.
- First indications are that a control issue has caused the target to malfunction in such a way that the target was able to get stuck.

- Theory at the moment: (TBC)
  - Target positioning system has malfunctioned.
    - This failure mode has not been observed before (In tens of millions of actuations!)
    - Depending on the exact failure mode there are several new features in the Phase 2 controller that should prevent this from recurring.

- We have a live spare target in R78 – T2 - The one that is currently running the tests. ISIS have previously agreed that this target can be used as a live spare.
- However because we are in the middle of running some tests in R78 and because ISIS is in the middle of the user run we will need to wait until the ISIS shutdown before we can swap the T2 target in.
- We will also take the opportunity to upgrade to the Phase 2 control electronics that is currently under test in R78.

END