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Laser Scanning for the replacement of EVB2 in the ISIS Synchrotron

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ISIS
Survey & Alignment

- The ISIS pulsed neutron and muon source at the Rutherford Appleton Laboratory in Oxfordshire is a world-leading centre for research in the physical and life sciences.
- It is owned and operated by the Science and Technology Facilities Council

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- Comprises a 70MeV LINAC, Synchrotron, 2 Extracted Proton Beamlines (EPBs) and 41 Instruments
- ISIS has been operating since 1984
- The second EPB and Target Station (TS2) was added in 2009

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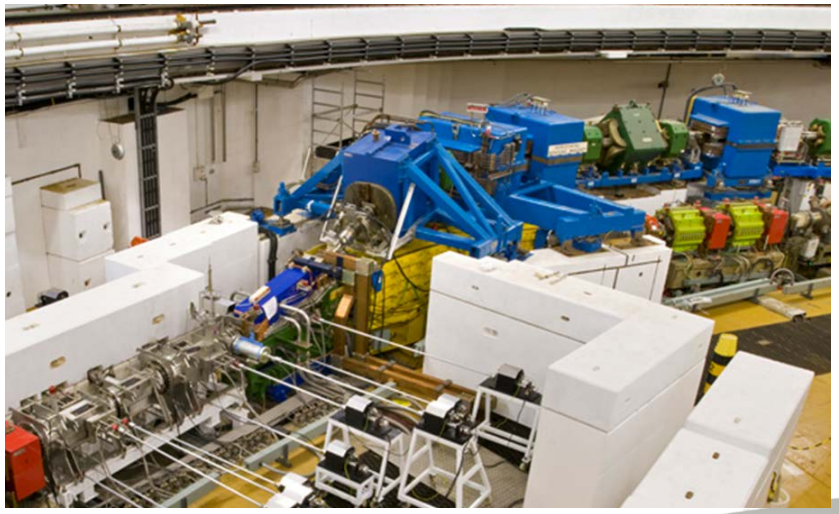
EVB2 Replacement Project

- EVB2 is a large vertical bending dipole magnet located in the EPB1 extraction line of the synchrotron
- The magnet is over 30 years old and has become increasingly unreliable
- Water leaking from EVB2 was found to have caused significant damage to the large dipole magnet beneath it



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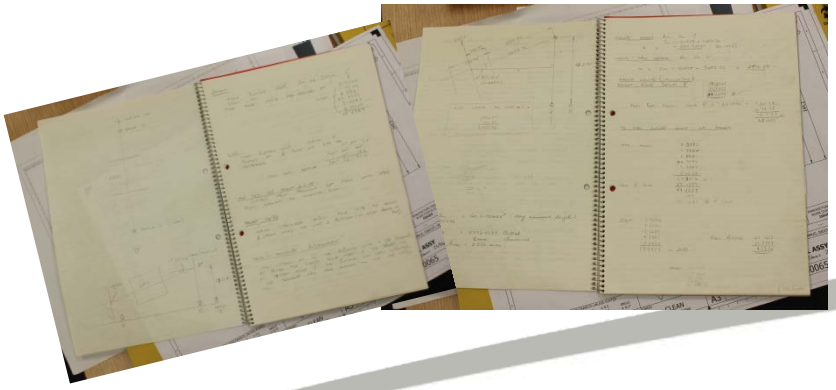
- Therefore, in late 2013, a project was put in place to replace the existing EVB2 magnet
- The scope of the project included procuring a new EVB2 magnet and frame which would replace the existing magnet
- The existing magnet could then be assessed and refurbished or replaced to act as a ‘drop-in’ spare
- From a survey and alignment point of view, this is where the headaches started

- The existing magnet was installed during the original construction of the synchrotron and EPB1 and was aligned using optical instrumentation on a direct line of sight along the beamline
- There are no discernible fiducial marks on the magnet, and very limited data or records have been found relating to the initial installation



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- There are two sockets for Taylor Hobson spheres mounted on the ‘inside’ side of the frame, but again no information was found detailing how the sockets related to the magnets position or the beam

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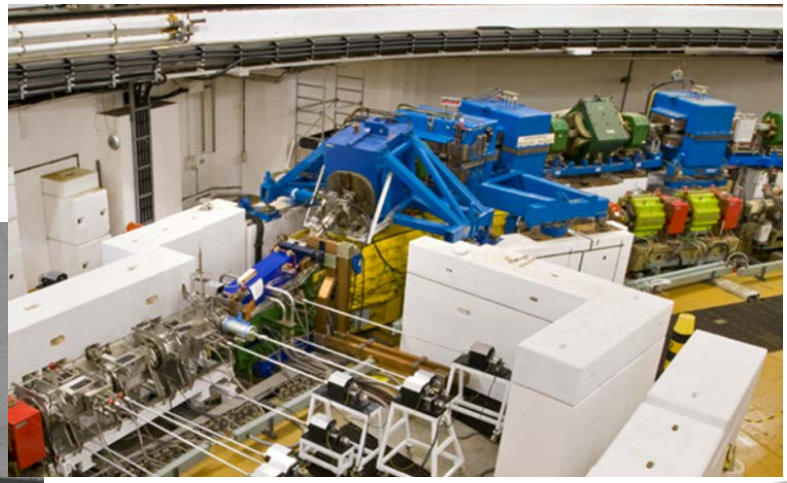
- Access problems to EVB2
  - High radiation area immediately upstream, ‘dose rate’ in order of 100µSv/hr
  - Magnet at ‘high level’ mounted above Synchrotron dipole



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Survey solution

- Fundamentally, replacement EVB2 magnet must match to fit the existing flight tubes up- and downstream
- Solution was to set-up and pre-align the replacement EVB2 by ‘reverse engineering’ the existing alignment
- Difficulties of access to existing EVB2 (high dose rates and elevated position) ruled out using AT401 Laser Tracker
- In-situ EVB2 surveyed using Trimble FX Laser Scanner

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- Trimble FX is a phase shift laser scanner, which when we bought it (Feb 2014) offered significantly better accuracy and scan data quality than most, if not all, terrestrial laser scanners on the market.
- At ISIS we also have access to both a GOM and a CreaForm white light scanning systems, as well as a FARO Edge ScanArm.
- These systems offer better accuracy than the FX scanner, but share the disadvantage of the Laser Tracker in requiring greater access, and longer times, on and around the scanned item.

- Manufacturer quoted accuracies for the FX are:
  - Range uncertainty . . . . . 1 mm @ 15 m single pass (on 90% reflectivity)
  - Distance accuracy (std dev.) . . . . . 0.6 mm @ 11 m
    (on 90% reflectivity) 0.8 mm @ 21 m
    2.4 mm @ 50 m
  - Position accuracy . . . . . 0.4 mm @ 11m
    0.8 mm @ 21m
    2.0 mm @ 50 m
  - Angle uncertainty . . . . . <30 arc second
    (1.6 mm @ 11 m; 3 mm @21 m; 8 mm @ 50 m)
  - Angular resolution . . . . . 8 sec

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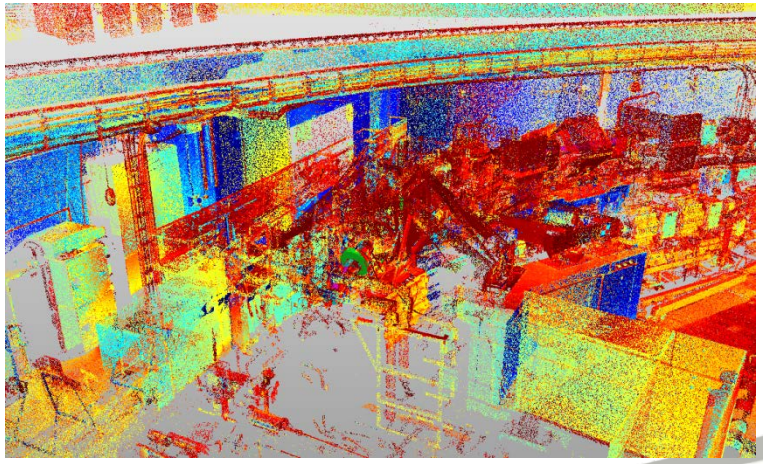
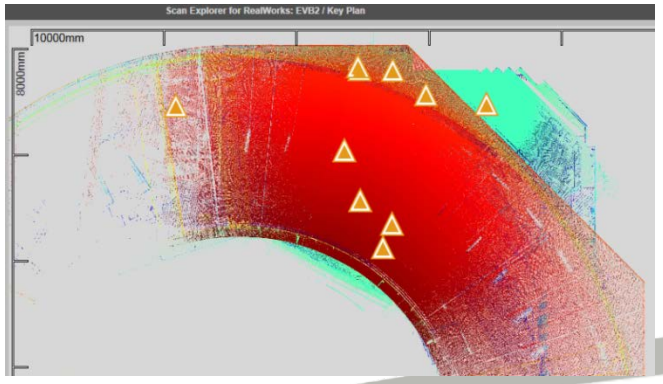
- The scanning process on site, within the Synchrotron, required 10 scans – each taking about 45 minutes.
- Because we weren't under significant time pressure we probably over-scanned the area, but even with this number of scans (c 400M points) we still found blackspots where we had no or very little data





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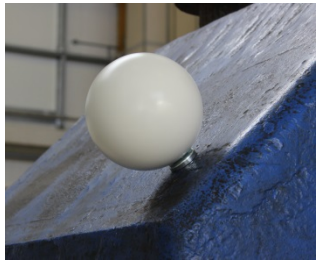
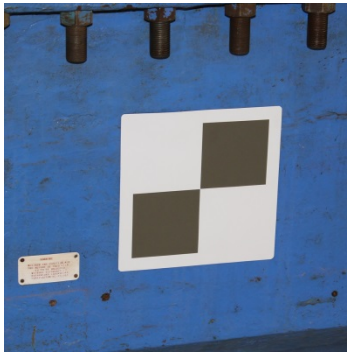
- The separate scans were registered using visible targets common to several scans, including
  - Hubbs Precision Scan Sphere (PSS)

  - Reference spheres



  - Chequerboards



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- All the scan data was processed using Trimble RealWorks®
  - The software can automatically identify and abstract the control targets, spheres of a known diameter and black and white chequerboards
  - Pairs of targets common to two or more scans are then identified and a least-squares adjustment is performed using the corresponding targets
  - The adjustment results in a set of scans which are ‘bundled’ together as a registered point cloud

- The overall results for the scan registration were
  - 10 STATION(S) - Mean Distance: 0.32 Max Distance: 0.61
  - 28 TARGET(S) - Mean Distance: 0.32 Max Distance: 1.10

Example scan results for individual scan registration (Scan 1)

EVB2_2015_7_30_001 - 15 Scanned Objects - Mean Distance: 0.39

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
001	038	5	0.24 mm	-0.00 mm	0.20 mm	-0.13 mm	0.17 mm	8691.83 mm
S3fx	039	4	0.27 mm	0.18 mm	-0.19 mm	-0.07 mm	0.18 mm	8692.22 mm
S2fx	040	3	0.23 mm	-0.12 mm	-0.17 mm	-0.09 mm	0.16 mm	4188.34 mm
S23fx	041	5	0.27 mm	0.24 mm	0.14 mm	-0.00 mm	0.17 mm	2649.91 mm
005	042	4	0.15 mm	-0.07 mm	-0.03 mm	0.13 mm	0.20 mm	2619.10 mm
008	045	3	0.36 mm	-0.12 mm	0.31 mm	0.15 mm	0.29 mm	6181.84 mm
009	046	3	0.13 mm	0.10 mm	0.07 mm	-0.04 mm	0.22 mm	6448.14 mm
007	044	4	0.25 mm	-0.23 mm	0.08 mm	0.01 mm	0.22 mm	4528.51 mm
006	043	4	0.25 mm	0.23 mm	0.11 mm	0.04 mm	0.21 mm	4979.20 mm
010	047	3	0.21 mm	0.02 mm	0.01 mm	-0.21 mm	0.24 mm	8178.88 mm
WIRP2	052	5	0.44 mm	-0.38 mm	-0.04 mm	0.21 mm	0.22 mm	6511.36 mm
RP5	048	4	0.89 mm	0.82 mm	-0.36 mm	0.02 mm	0.25 mm	8474.54 mm
RP4	049	5	0.99 mm	-0.91 mm	0.38 mm	0.14 mm	0.25 mm	10788.90 mm
RP3	050	4	0.79 mm	0.63 mm	-0.47 mm	-0.10 mm	0.40 mm	14043.40 mm
RP6	051	4	0.33 mm	-0.00 mm	-0.29 mm	-0.15 mm	0.26 mm	8633.57 mm

Trimble
Trimble RealWorks Advanced Modeler ©

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- Using a number of scanned PSS targets which were placed on known laser tracker control points, the registered pointcloud was then transformed to the existing Synchrotron Survey Control network

Best-Fit Transformation1 (Summary)
EVB2 Georeferencing Scans::Registered Targets.txt to EVB2 Georeferencing Scans::EVB2 Control.txt
29/09/2016 12:30:19

Results	X	Y	Z	Mag
Count	8	8	8	8
Max Error	0.62	0.68	0.33	0.79
RMS Error	0.35	0.37	0.22	0.55
StdDev Error	0.38	0.39	0.24	0.59
Max Error (all)	0.62	0.68	0.33	0.79
RMS Error (all)	0.35	0.37	0.22	0.55
	Unknowns	6	Equations	24
Transformation				
Translation (mm)	0.02	-0.01	2.41	2.41
Rotation (deg)				
Fixed XYZ	-0.0031	0.0054	0.0001	
Euler XYZ	-0.0031	0.0054	0.0001	
Axis-Angle	-0.496162	0.868164	0.010716	0.0063
Matrix				
	1.000000	-0.000001	0.000095	0.019032
	0.000001	1.000000	0.000054	-0.013627
	-0.000095	-0.000054	1.000000	2.405531
	0.000000	0.000000	0.000000	1.000000
Scale Factor				1.000000
Working frame	EVB2 Georeferencing Scans::WORLD			

Best-Fit Transformation1 (Details)
EVB2 Georeferencing Scans::Registered Targets.txt to EVB2 Georeferencing Scans::EVB2 Control.txt
29/09/2016 12:30:19

Name	On	Nom X	Nom Y	Nom Z	Act X	Act Y	Act Z	Wt X	Wt Y	Wt Z	dX	dY	dZ	dMag
S1fx	X	-4770.72	20221.51	32.01	-4770.29	20221.13	31.68	1.000	1.000	1.000	0.43	-0.38	-0.33	0.66
S2fx	X	8024.94	19162.55	32.84	8025.44	19162.91	33.06	1.000	1.000	1.000	0.50	0.36	0.22	0.65
S3fx	X	17760.97	10781.68	33.30	17760.60	10782.36	33.47	1.000	1.000	1.000	-0.37	0.68	0.17	0.79
S23fx	X	13689.42	15345.65	32.07	13689.28	15345.98	32.23	1.000	1.000	1.000	-0.14	0.33	0.16	0.39
RP3	X	22165.77	7693.81	-287.41	22165.87	7693.58	-287.51	1.000	1.000	1.000	0.10	-0.23	-0.10	0.27
RP4	X	20877.78	11525.70	-267.98	20877.85	11525.46	-268.19	1.000	1.000	1.000	0.07	-0.24	-0.21	0.32
RP5	X	19393.67	13828.89	-232.40	19393.72	13828.64	-232.60	1.000	1.000	1.000	0.05	-0.25	-0.20	0.33
WIRP2	X	5314.96	14617.72	463.50	5314.34	14617.46	463.79	1.000	1.000	1.000	-0.62	-0.26	0.29	0.74

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- Having completed the registration process, the pointcloud, trimmed to include just the EVB2 and frame (c. 40.5M points), was exported as an .e57 format file
- The .e57 file was imported into CloudCompare for ‘cleaning’ and reduction of extraneous ‘noise’
- The ‘clean’ cloud (c.26.5M points) was then imported back into RealWorks

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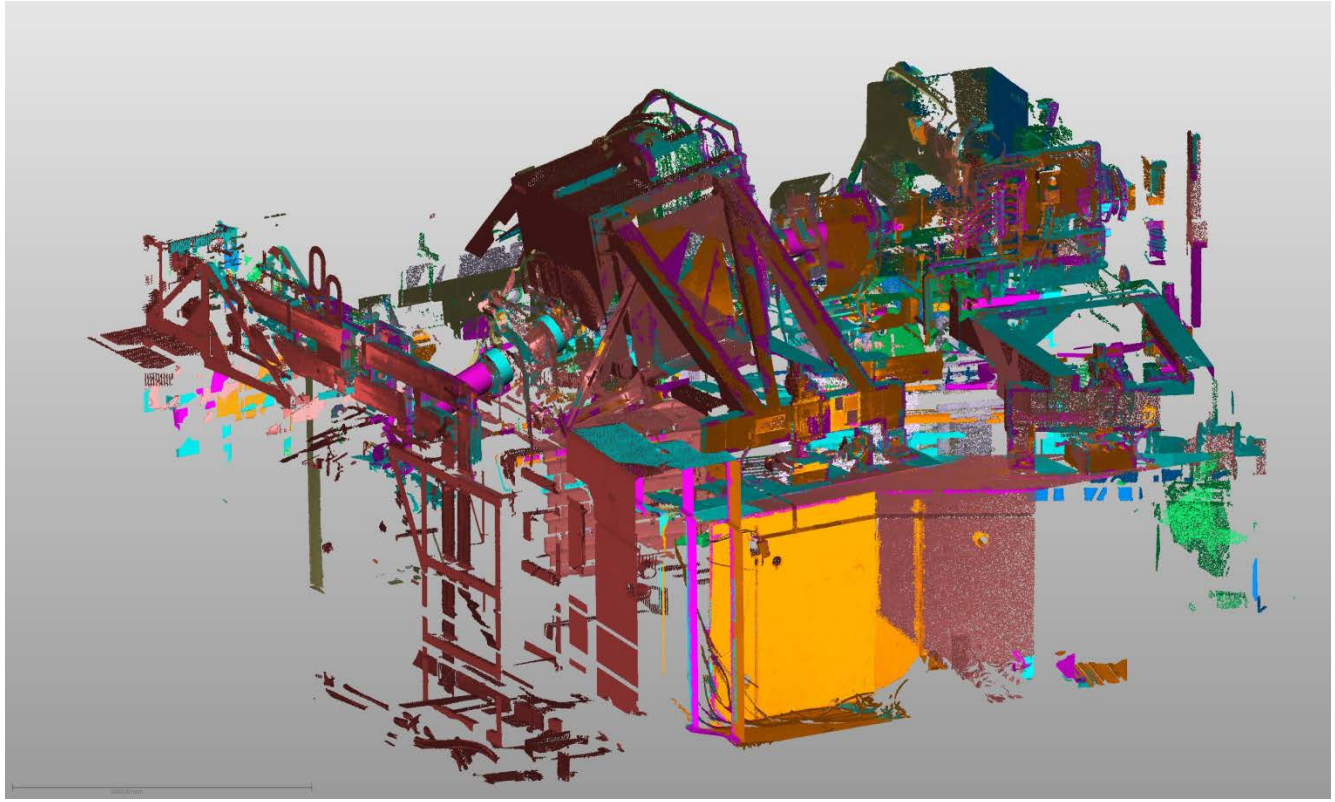

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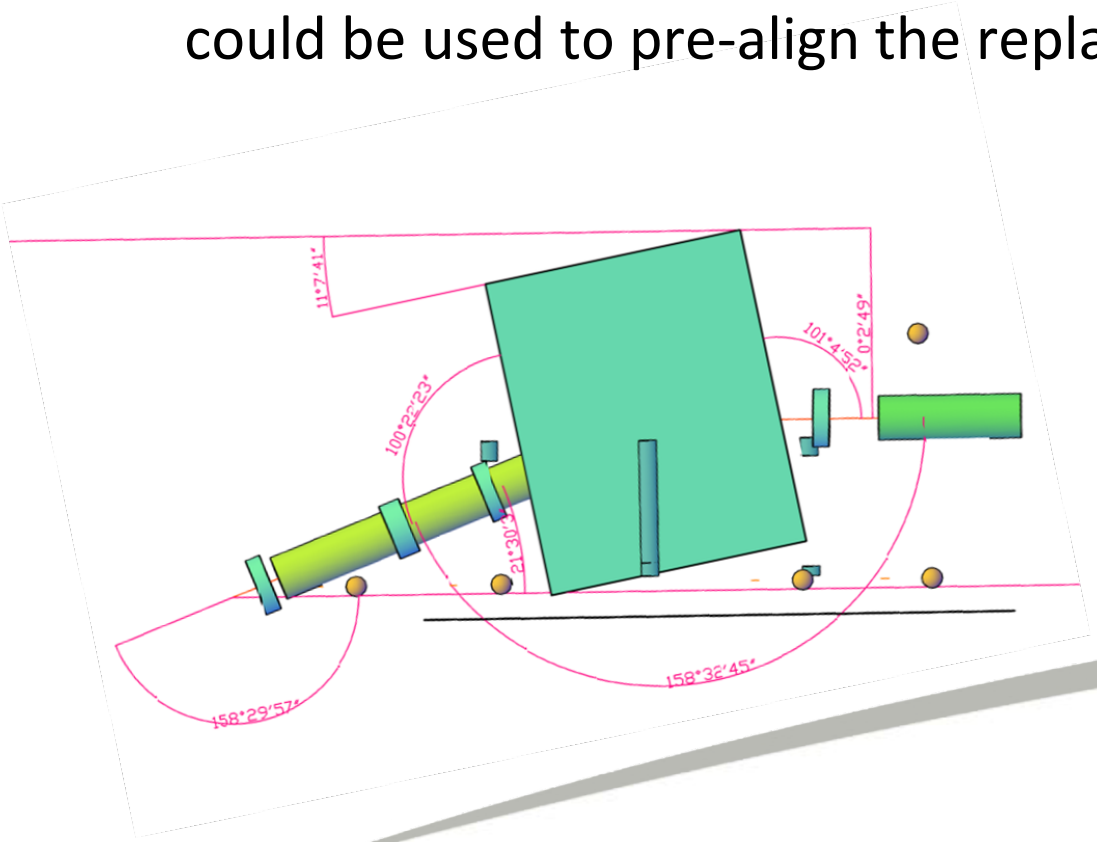
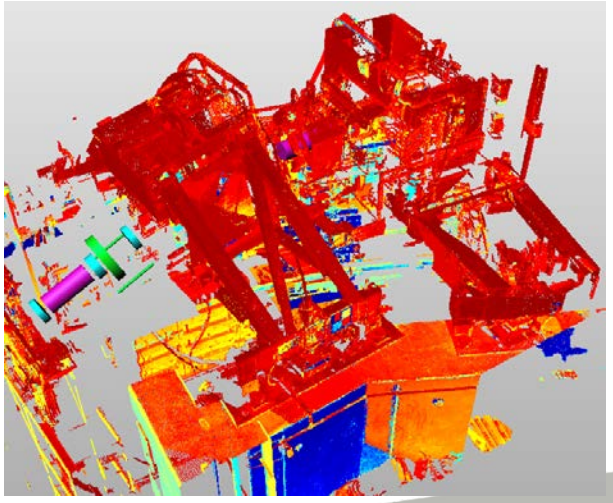
- Using the pointcloud modelling functions within RealWorks we were then able to abstract key dimensions and positions for the existing, in-situ, EVB2 magnet which could be used to pre-align the replacement magnet.





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- We were also able to abstract some information to compare against known measurements, in order to give some confidence in the accuracy of dimensions taken from the pointcloud
  - From the original (incomplete) 1984 alignment notes, the magnet was set to a tilt of 11°07’34.5” from horizontal. When we abstracted a ‘best-fit’ plane (5,500points, 0.29mm RMS Deviation) from the scan data we had a tilt of 11°07’41.3”

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- We also had the original measured distance between the two TH sockets on the magnet frame.
  - The measurement recorded in original notes was 1395.41mm,
  - The dimension when taken from the scan data was 1395.36mm.
  - When measured using the AT401, the dimension was 1395.47mm

- Having obtained the alignment details of the in-situ magnet, we have been able to pre-align the replacement EVB2 to match
- However, with no information available to conclusively determine the existing EVB2 relationship to its kinematic mounts, we still anticipate needing some additional, last minute or ‘dynamic’ adjustment when the replacement is installed

- At present, the original EVB2 remains operational and a decision has been taken to delay installation of the replacement until absolutely necessary

- Final results and assessment of the success (or otherwise) of using the scan data to pre-align the replacement magnet are therefore not yet available

- Thank you

  - For further information about ISIS please see
    - http://www.isis.stfc.ac.uk/about/aboutisis.html

  - Also worth a look is the series of YouTube films "Accelerators for humanity" produced by the Royal Institution
    - http://richannel.org/collections/2016/particle-accelerators-for-humanity