MICE Target Simulation

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Contents

Abstract

Simulation of the pion production coming out from the MICE target using the MARS simulation software and implementation of this simulation into the MICE Monte Carlo software.

1 Motivation

Non trivial discrepancies in the data versus Monte Carlo comparison have justified the necessity to reconsider the pions momentum distribution used as primary input of the MICE Monte Carlo. The former model consisted in a fit done with three Gaussian of a pion distribution produced in 2008 with a earlier version of the MARS simulation software. Lack of documentation on this first study made it hard to evaluate the goodness of the model that shows a peculiar hard cut in the distribution.

The MICE target has been described in its major components using the MARS simulation software.

2 The MICE target in the ISIS proton beam

The MICE target operates parasitically on protons undergoing acceleration within the ISIS synchrotron, dipping into the low-density halo of the beam on selected pulses just prior to their extraction, with a 1 Hz frequency. It is designed as a bored TiAl cylinder with inner radius 2.275 cm and outer radius 2.975 cm. The resulting thickness of material for proton collisions is significantly lower than one interaction length (approx 27.8cm for titanium), giving an interaction probability of order 1%. As a result, order 1E12 simulated ISIS protons are required for sufficient statistics to fit the momentum distribution precisely.

The ISIS synchrotron circulates two beam bunches of approximately 1.4E13 protons each per cycle, with these undergoing close to 10,000 revolutions before extraction in a circulation time of 10ms. Proton beam-size shrinking between radii of 67mm and 48mm during it's acceleration through the synchrotron results in proton collision energy and beamwidth both varying in time with respect to the initial ISIS proton injection trigger, as well as due to small field fluctuations. Hence the target undergoes many proton collisions of between 650MeV and 800MeV collision energy during each dip (See Table 2).

Furthermore due to the field changes in the synchrotron, the ISIS beam often drifts from the well-defined beam center, such that the beam centre displacement (BCD) figure recorded is only a nominal value.

As noted in [4] the target is operated through the RATS control software, allowing the user to alter both BCD and User Delay (defined from the machine start trigger + $(2^n \times 20ms) - 15ms$, with n some integer) such that dips travelling further to achieve lower BCD may operate with reduced User Delay to compensate.

ISIS Beam Energy after injection					
Time after injection (ms)	7.0	7.1	7.2	7.3	7.4
Proton Energy (MeV)	615.59	626.53	637.25	647.73	657.96
Time after injection (ms)	7.5	7.6	7.7	7.8	7.9
Proton Energy (MeV)	667.93	688.62	687.02	696.12	704.90
Time after injection (ms)	8.0	8.1	8.2	8.3	8.4
Proton Energy (MeV)	713.35	721.47	729.23	736.64	743.68
Time after injection (ms)	8.5	8.6	8.7	8.8	8.9
Proton Energy (MeV)	750.33	756.60	762.48	767.95	773.01
Time after injection (ms)	9.0	9.1	9.2	9.3	9.4
Proton Energy (MeV)	777.65	781.87	785.66	789.02	791.94
Time after injection (ms)	9.5	9.6	9.7	9.8	9.9
Proton Energy (MeV)	794.41	796.44	798.02	799.15	799.83

Table 1: Time after injection (ms) vs Proton Energy in the ISIS beam (MeV). Interactions from target dipping occur over this time range.

3 MARS simulation

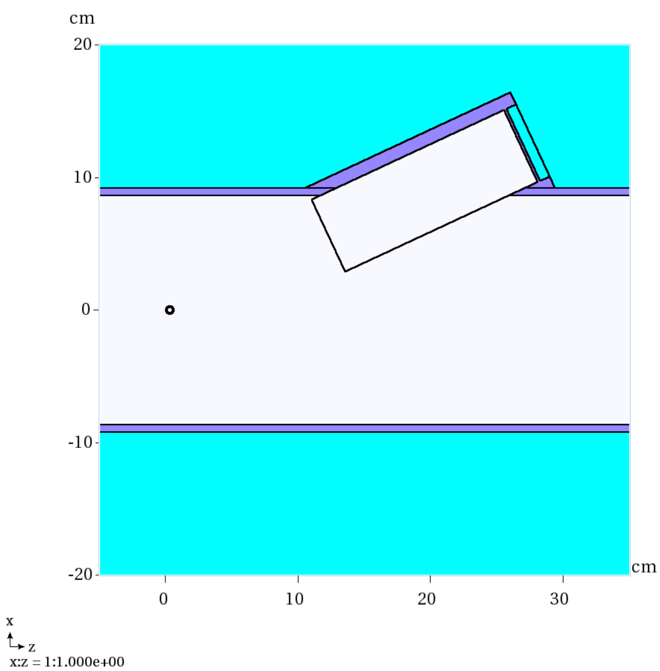


Figure 1: Design of the target in the MARS simulation. STST304 structures are shown in purple, with the pink ring at (0,0) the cross-sectional slice of the TiAl target, blue is air and white is vacuum. Cross-section taken at y=6cm.

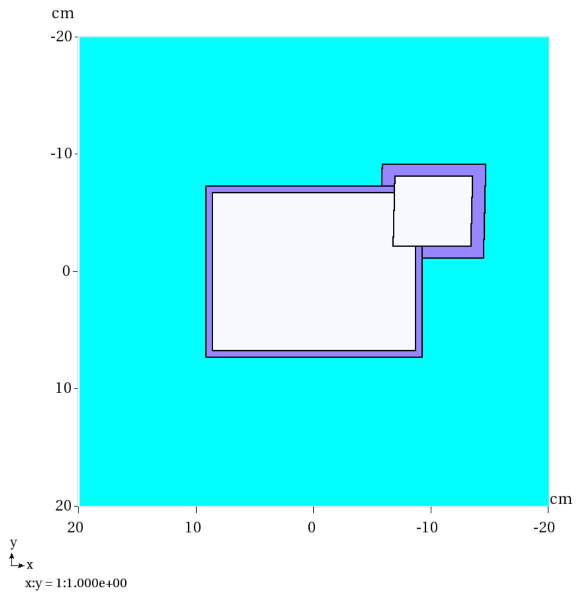


Figure 2: Design of the target in the MARS simulation. STST304 structures are shown in purple, blue is air and white is vacuum. Cross-section taken at z=22cm.

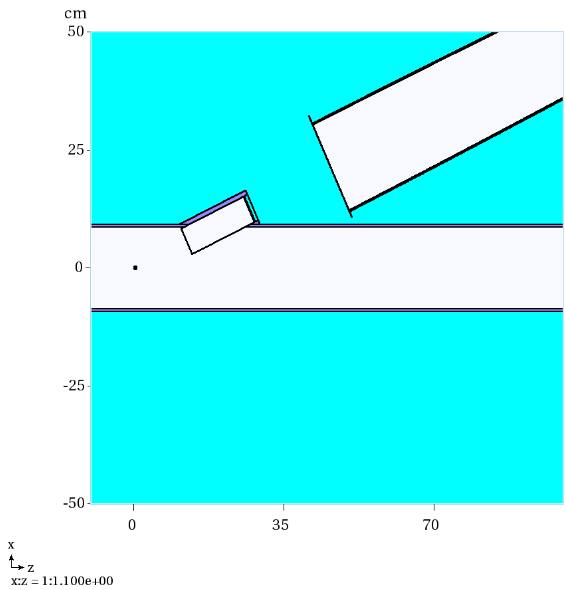


Figure 3: MARS geometry of the MICE target inside the ISIS beampipe, alongside the MICE beampipe.

The design of the MICE target, in particular the surrounding structure, is defined as in Fig. 1. The presented design has been based on schematics [5][6][7] and surveys [8][9]. The MICE beamline is orientated at 25 deg with respect to the ISIS beamline section where the target is located. In addition to the cylindrical bored-target structure from the previous model, various features of the surrounding ISIS beampipe structure have been included, such as the surrounding beampipe and target window structure oriented at 25 degrees toward the MICE beamline, as shown in Figs 1, 2. An initial section of the MICE beampipe up to the Q1 aperture (approx 2.5m downstream) is also modelled in MARS as in 3. For efficient runtime, particles are selected at 1m from the target IP inside the MICE beampipe. This produces the resulting pion distribution which is fitted and passed to G4BL. Comparison was made with MARS output taken 2m downstream, however this showed little change to the observed momentum distribution to be fitted.

As both BCD and User Delay are altered live by the MICE operator to respond to ISIS beam drift & target deterioration, modelling a dip cycle to replicate the target operation throughout the entire MICE data collection is not possible. Instead a number of model iterations with varying proton energy and beamwidth have been simulated to compare pion production & momentum distribution, and results from downstream propagation. Pions produced for a given number of simulated beam protons at each energy are shown in fig. 4.

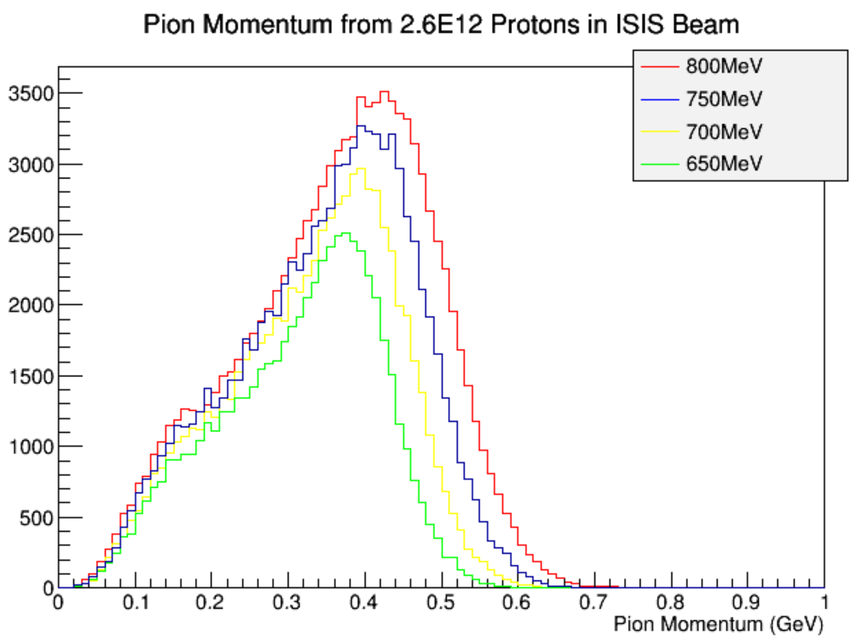


Figure 4: Momentum of π^+ produced in Proton-target collisions, taken 1m downstream in the MICE beamline.

4 MAUS simulation

The Monte Carlo in MICE is produced in a two-step process. In the first step a pion beam is produced according to an initial momentum distribution and is propagated using G4BL up to the bending dipole D2. After this point MAUS takes over propagating the particles (pions, muons and electrons coming from decays) through the remaining part of the beamline up to the EMR, passing through the cooling channel, according to the geometry and run selected to be simulated.

4.1 Monte Carlo and data comparison

A few figures of merit have been considered: time of flight of the particles between TOF0 and TOF1 and momentum distribution of pions and muons in the upstream tracker at station 5. Simulations have been produced for 140, 200 and 240 MeV/c nominal pionic beams, with further planned.

Output from simulations with initial proton energies of 650, 700, 750 and 800 were passed to MAUS, showing the effect on the beamline of any variation in collision energy. The impact of this was considered to be nominal, as MC results downstream have shown approximately the same normalised distributions irrespective of initial proton energy (see Figs 5,6,7,8), due to the dipole selection of the beam within the beampipe.

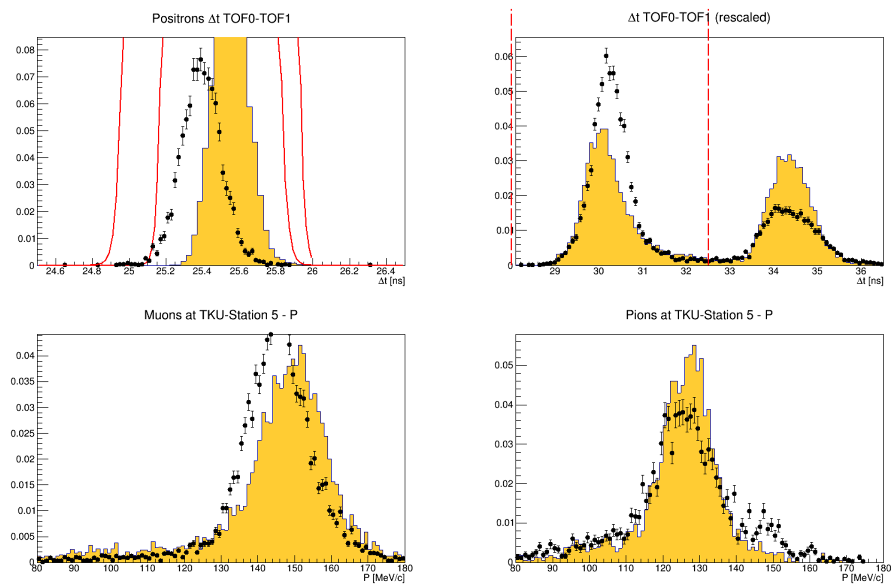


Figure 5: Output from fully propagated MAUS MC using a 650MeV simulated ISIS beam energy vs data. Beam settings used are for run 10049, with 3-140+M3-Test4 beamline.

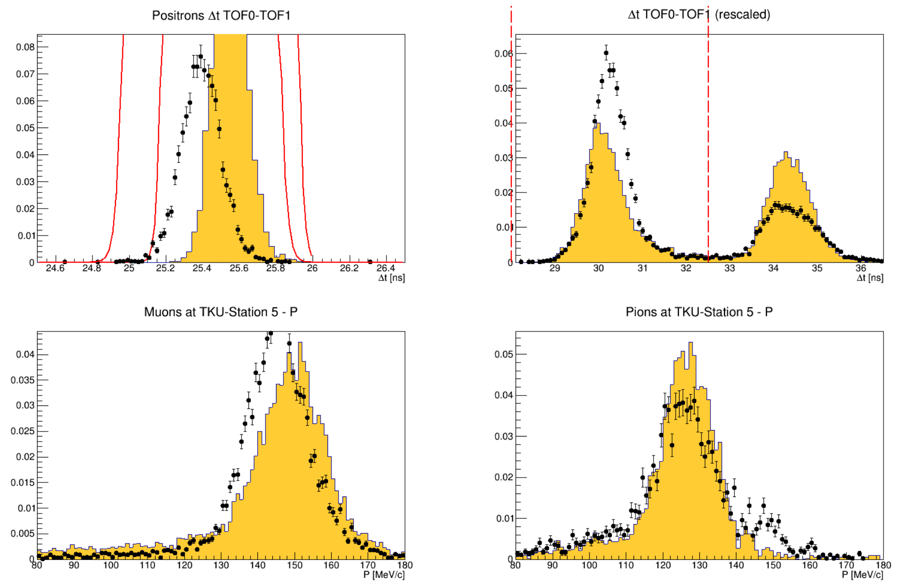


Figure 6: Output from fully propagated MAUS MC using a 700MeV simulated ISIS beam energy vs data. Beam settings used are for run 10049, with 3-140+M3-Test4 beamline.

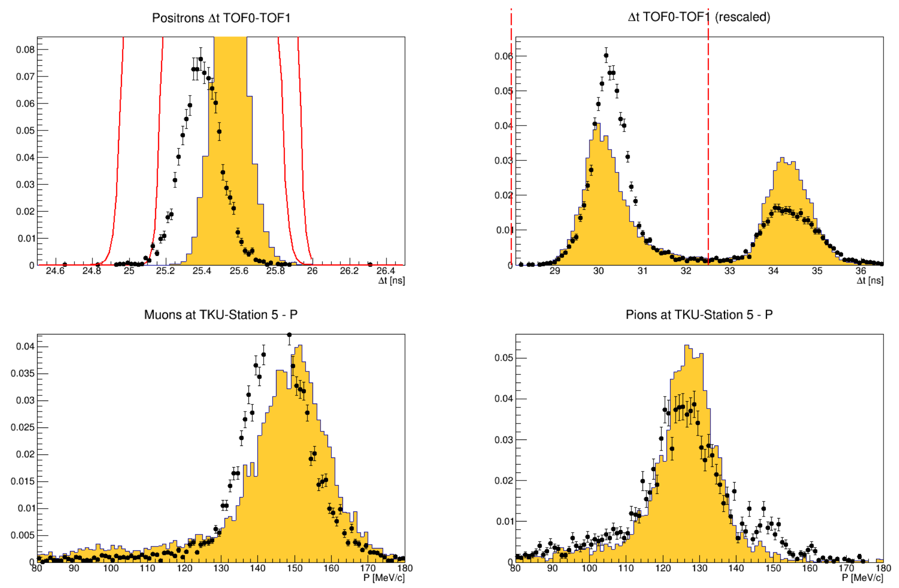


Figure 7: Output from fully propagated MAUS MC using a 750MeV simulated ISIS beam energy vs data. Beam settings used are for run 10049, with 3-140+M3-Test4 beamline.

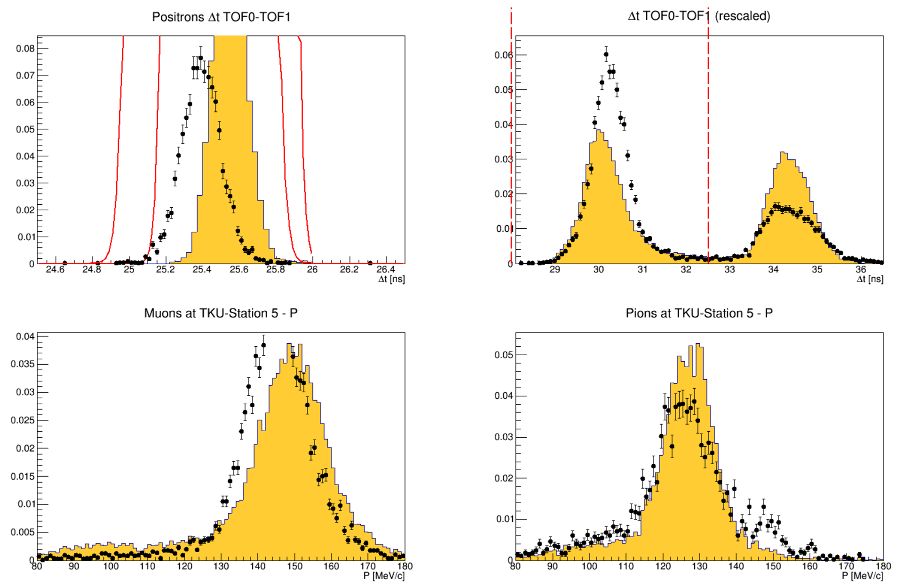


Figure 8: Output from fully propagated MAUS MC using a 800MeV simulated ISIS beam energy vs data. Beam settings used are for run 10049, with 3-140+M3-Test4 beamline.

There remain some significant deviations between the fully propagated MC and data, which are still under investigation.

5 Luminosity monitor

A luminosity monitor (LM) (Fig. 9, 10 and 11) has been designed and constructed to measure the particle rate close to the MICE target and determine the number of protons hitting the target as a function of depth. The LM is centred 10m from the target interaction point at an angle of -25 degrees, such that it observes particles at equivalent angle to the MICE beamline at 25 degrees. The LM response was simulated in Geant4 using an appropriate model based on Fig. 11, using an input of particles generated in MARS. This allowed an attempt at normalising the simulated target output with respect to the recorded LM readings for each run.

In practice the coincidence gates on the LM require coincident events of less than 10ns separation between LM1 & LM2, LM3 & LM4, or LM12 & LM34. The LM was modelled in Geant4 and the output from a MARS simulation of order E11 beam protons propagated through the model, however due to the strict coincidence requirements, the number of events was too low to be statistically significant. In comparison with recorded data, we observe approx. 2000 LM triggers per spill, with each spill consisting of two circulating proton bunches of 1.3E13 protons each. These bunches pass the target of order 1000 times per dip, suggesting approx.

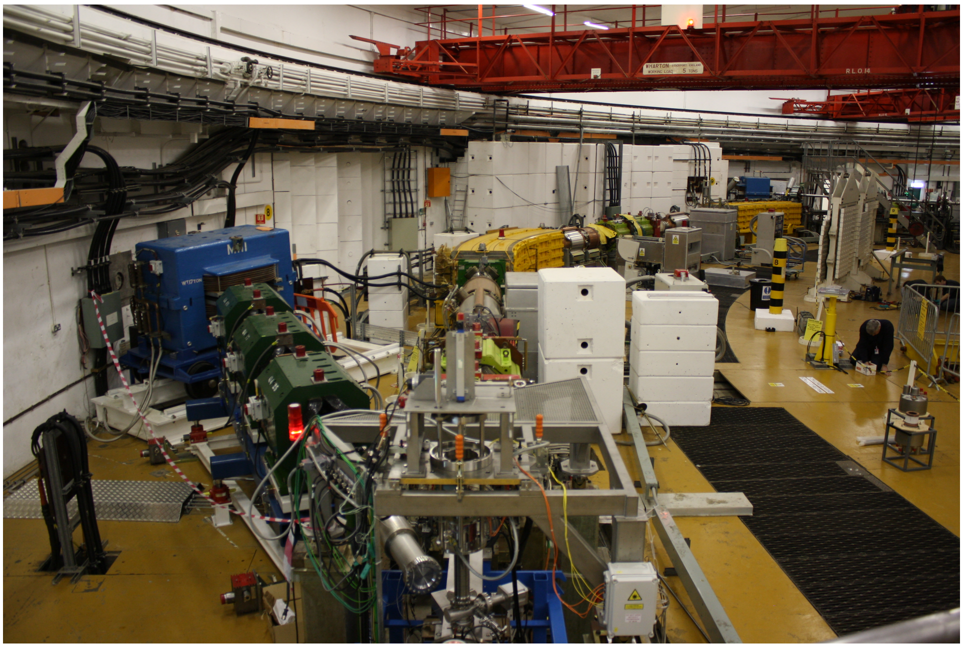


Figure 9: View of the ISIS synchrotron from above the target. MICE beam line on the left and luminosity monitor on the right 10 m away, standing on the top of the yellow turret.

Figure 10: The luminosity monitor encapsulated in a 2 inch plastic sarcophagus.

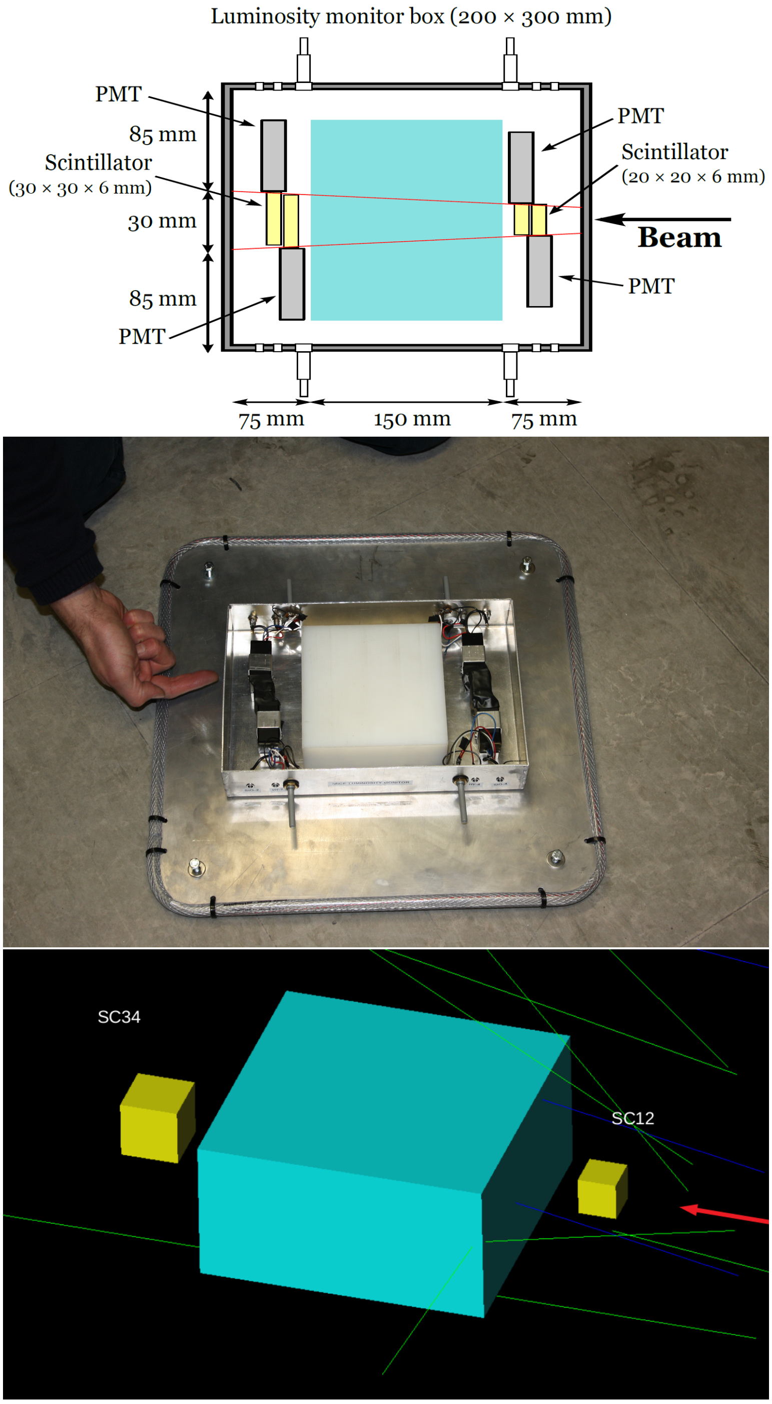


Figure 11: Design of the luminosity monitor, top, and the luminosity monitor box itself, middle. Bottom shows the LM modelled in Geant4, prior to inclusion of the plastic surround. <- bottom needs to be updated to the new model, including separate LM1,2,3&4 scintillators & plastic surround/box.

2E16 simulated protons should correspond to 2000 triggers, or equivalently a 1% probability of a coincidence event given 1E11 simulated beam protons. Work is underway to alter the Geant4 model such that the LM model is several orders of magnitude larger, hence decreasing the requirement for such a large number of simulated events.

6 Conclusions

There remain inconsistencies between the current fully propagated MC model and the data which are currently under investigation, however we have shown an independence of our observed distributions downstream on the initial proton beam energy, and hence to some degree, on the target.

References

[1] https://mars.fnal.gov/

[2] MICE note #216, http://mice.iit.edu/micenotes/public/pdf/MICE0216/MICE0216.pdf

[3] MICE note #242, http://mice.iit.edu/micenotes/public/pdf/MICE0242/MICE0242.pdf

[4] MICE note #480, http://mice.iit.edu/micenotes/public/pdf/MICE0480/MICE0480.pdf

[5] ISIS Survey Drawing 1-SI-6305-031-01-D, M113 Vacuum Vessel

[6] ISIS Survey Drawing 1-SI-6305-031-02-C, M113 Vacuum Vessel

[7] ISIS Survey Drawing 1-SI-6305-031-03-C, M113 Vacuum Vessel

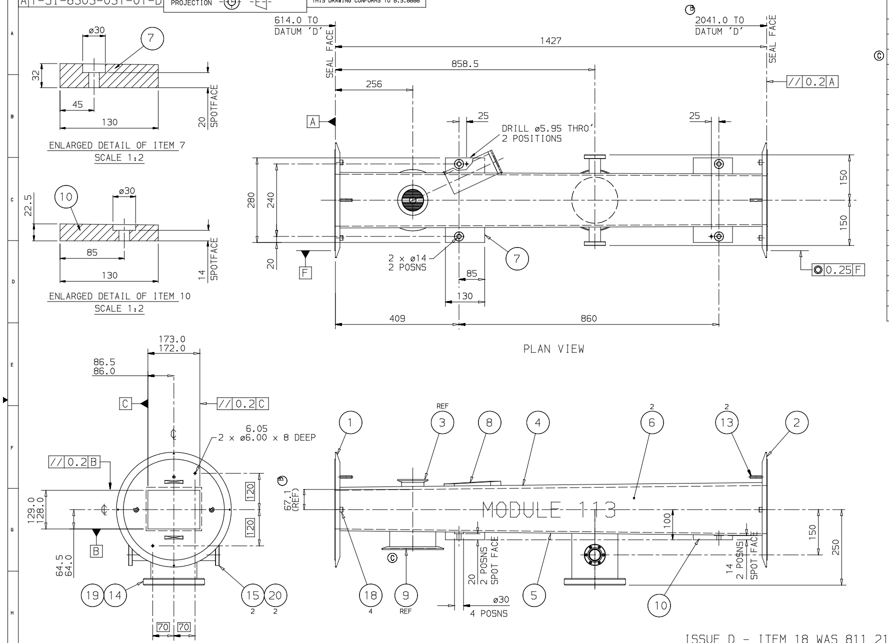
[8] ISIS Survey Drawing 0-SI-5100-105-04-I, Essential Geometry of ISIS

[9] MICE Beamline Decommissioning Survey Report

Appendices

ISIS Schematics and Survey Drawings

A 1-SI-6305-031-01-D | PROJECTION | THIS DRAWING CONFORMS TO B.S.8888



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3	THIS (SHT 3)	TOP PORT	1	_	_	ST.STL BS EN10088:PT 2 1.4301/AISI 304L
4	THIS (SHT 1)	TOP PLATE	1	_	_	ST.STL BS EN10088:PT 2 1.4301/AISI 304L
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14	THIS	TUBE O/D 152 x I/D 149	1	_	_	ST.STL BS EN10088:PT 2 1.4301/AISI 304L
15	THIS	TUBE O/D 38 x I/D 33.7	2	_	_	ST.STL BS EN10088:PT 2 1.4301/AISI 304L
16	THIS	ø2 STA.STEEL WIRE	AR	_	_	ST.STL BS EN10088:PT 2 1.4301/AISI 304L
17			_	_	_	
18	WDS 811-21620	BUTTON	4	_	_	SEE NOTE 4
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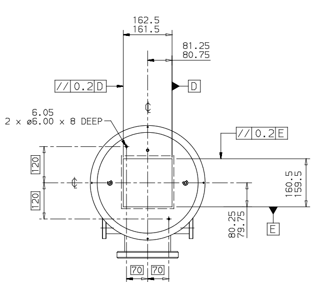

NOTES:-

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3. PAINT ON BOTH SIDE WALLS OF CHAMBER MODULE 113 IN 50 mm HIGH CHARACTERS USING EPOXY PAINT. WHERE SHOWN
4. AVAILABLE FROM WDS STANDARD PARTS POLLARD LANE LEEDS LS13 1EH Tel:- 0113 258 1333 Fax:- 0113 259 0649

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A	15JAN2004	---	SCL2238	JRH	---	MANUF.

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THE CENTRAL LABORATORY OF THE RESEARCH COUNCILS RUTHERFORD APPLETON LABORATORY, CHILTON, OXON OX11 0QX.

SHEET 1 OF 3 SHEETS

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MICE SP7 ISIS

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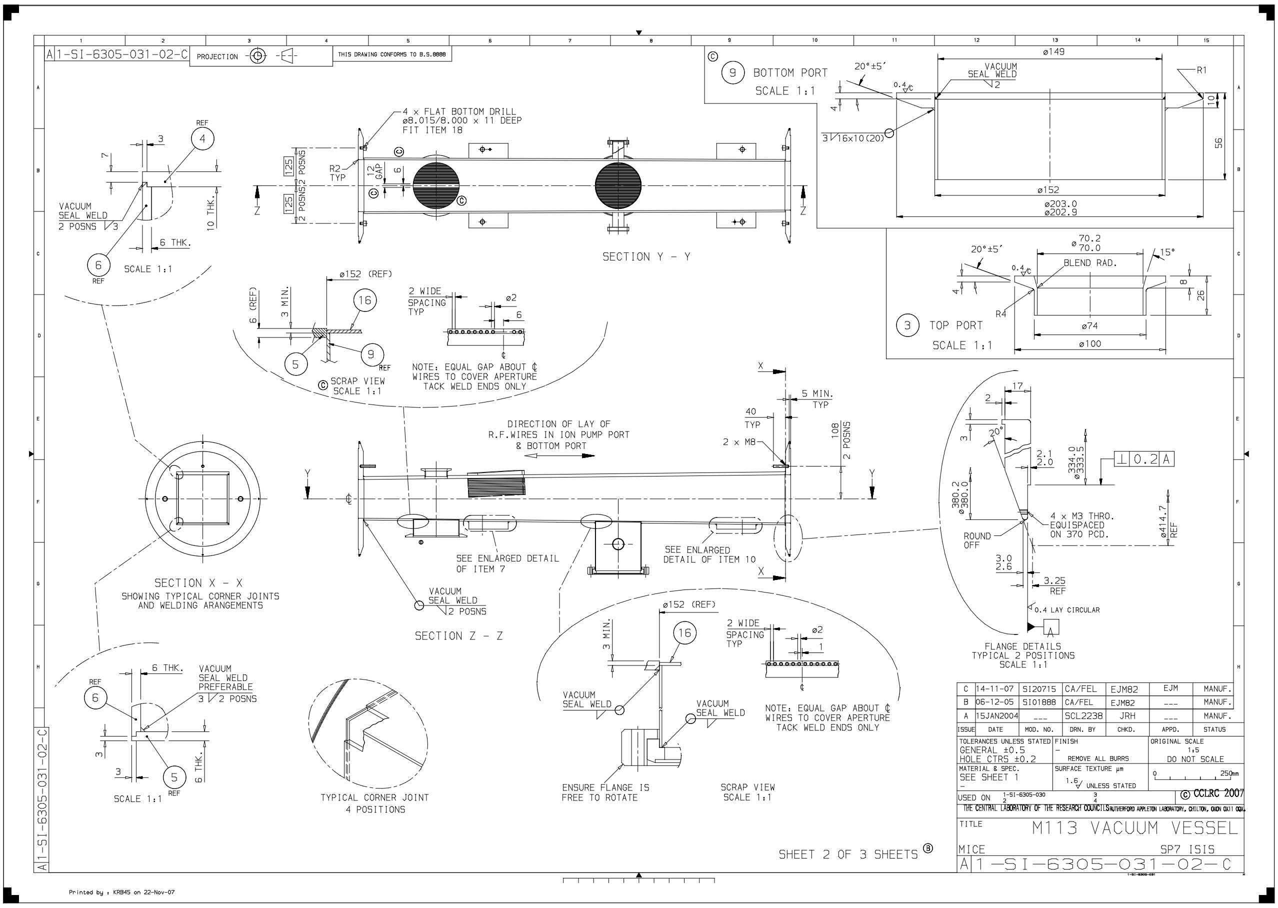

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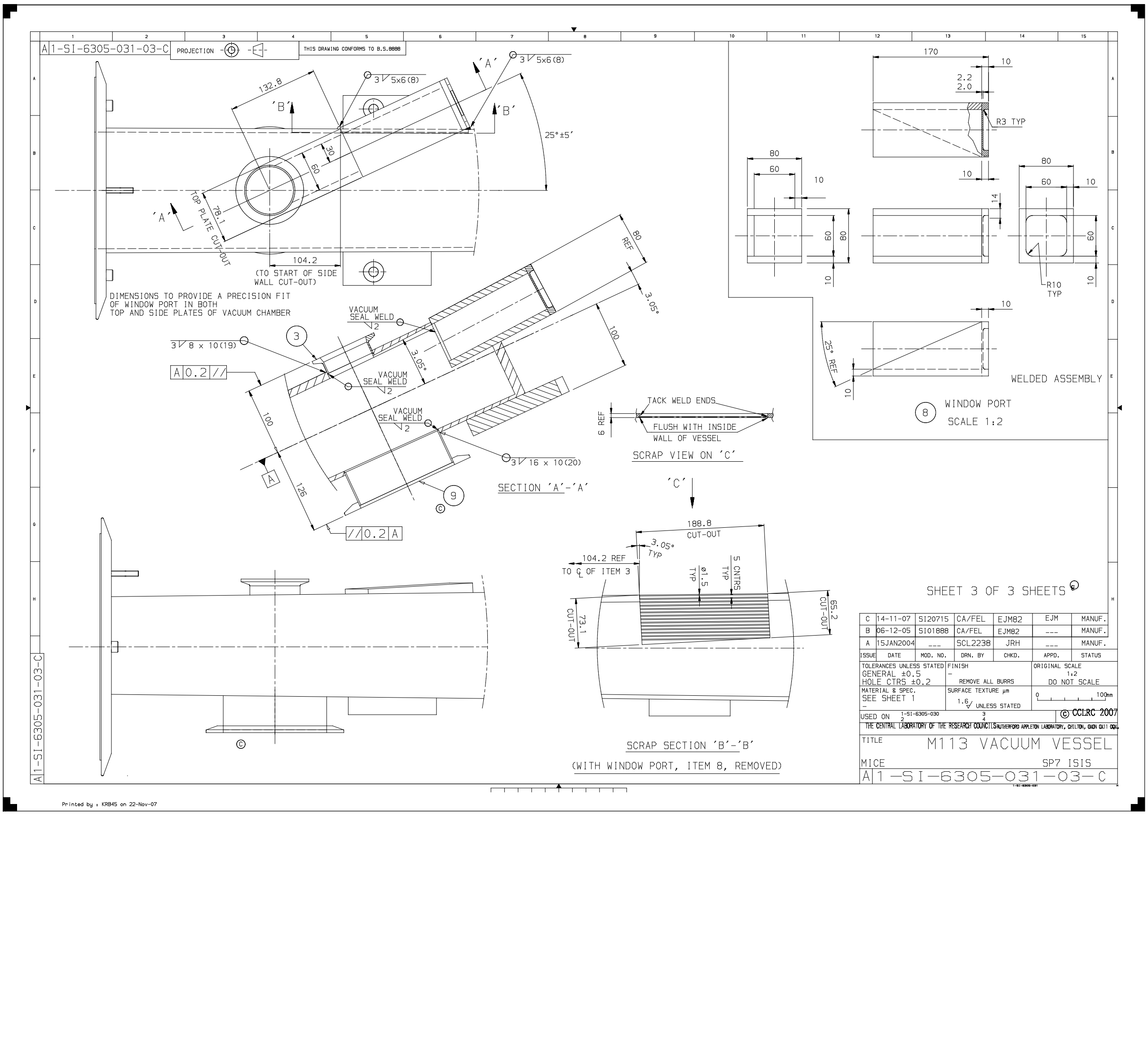

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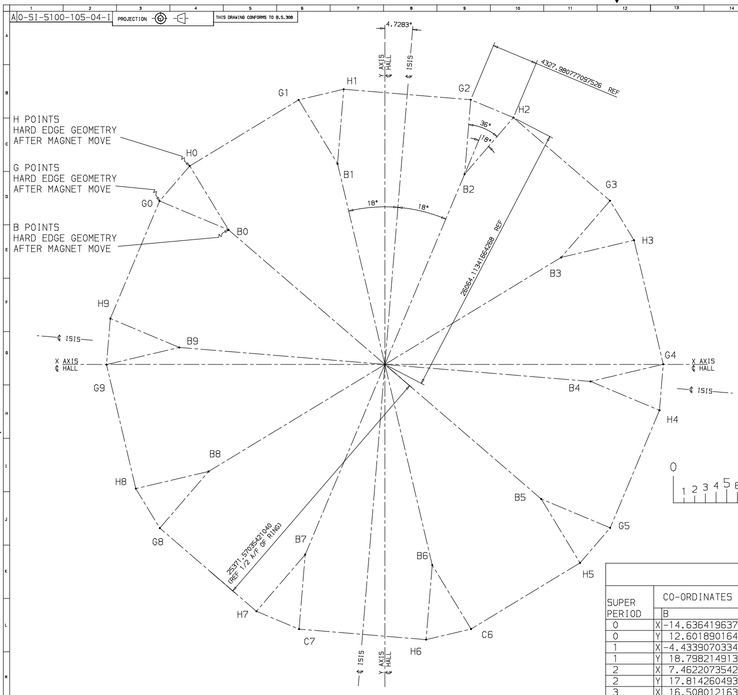


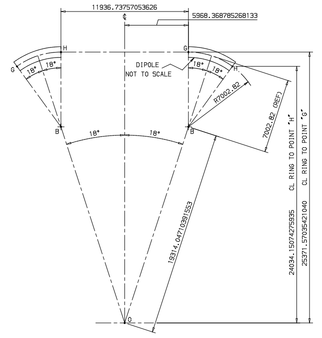
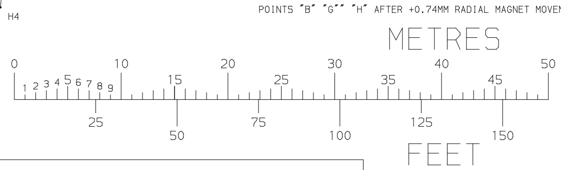


FIG.1b. "HARD EDGE" GEOMETRY
POINTS "B" "G" "H" AFTER +0.74MM RADIAL MAGNET MOVEMENT



RING GEOMETRY

CO-ORDINATES IN METRES ALL WITH Z OF -0.603

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0	X	-14.6364196374051	X	-21.0954522264142	X	-18.2715625415826
0	Y	12.6018901649732	Y	15.307511344392	Y	18.5873077793597
1	X	-4.43390703348312	X	-8.06904993766055	X	-3.85665921739619
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6	X	4.43390703348312	X	8.06904993766054	X	3.8566592173962
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7	Y	-17.8142604936077	Y	-24.7932484511287	Y	-23.1210826015664
8	X	-16.508012163795	X	-21.0771616543328	X	-23.3238035230774
8	Y	-10.0258640491613	Y	-15.3326861571199	Y	-11.6334946345667
9	X	-19.2483174134448	X	-26.0641087727272	X	-25.7073500024538
9	Y	1.59207169547918	Y	-1.55588899262545E-02	Y	4.29769287489788

"B" AND "G" AND "H" POINTS
HARD EDGE GEOMETRY
AFTER RADIAL MAGNET MOVE 0.74MM
FOR X,Y,Z COORDINATES SEE RING GEOMETRY TABLE
SEE SHEET 1 FOR OVERALL VIEW OF ISIS

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TITLE ESSENTIAL GEOMETRY OF ISIS

ISIS ---

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